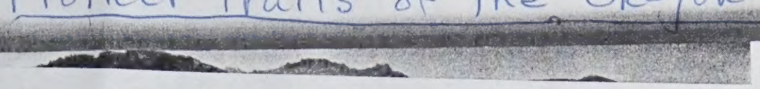
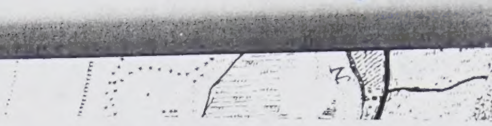
Pioneer Trails of the Oregon Coast.





Samuel N. Dicken
OHS- 1971

Trails of the Northern Oregon Coast

FOR the most part the early trails on the northern coast served two areas of settlement, the Clatsop Plains and the Tillamook Plain; a few other settlements were established at various points along the trails. Settlement began on the Clatsop Plains in 1840 and on the Tillamook Plain about ten years later. The main routes of travel to and from the Willamette Valley formed a crude circle. Astoria, Fort Vancouver, the middle Willamette Valley, the upper Yamhill River, the Nestucca River, and Tillamook were "points" on the circle. When the missionary, J. H. Frost, traveled from Clatsop Plains to the missions in the middle Willamette Valley in 1840 he went by canoe up the Columbia and Willamette rivers and returned the same way; in a ater journey he traveled overland via Tillamook, the Nestucca, and the Yamhill rivers. Ten years later the illamook pioneer, Warren Vaughn, made the comlete circle.[14] The descriptions of trails and settlements follow are arranged by sections from north to south, rresponding to the U.S. Geological Survey quadranes, which are used as base maps.

THE CLATSOP PLAINS

The Clatsop Plains (Fig. 10) extend from Tillaok Head (Seaside) northward to the Columbia er, and consist of long, narrow, parallel, sandy es with intervening lower areas, some of them marshy. A number of long, narrow lakes occur here of which Coffenbury, Smith, Cullaby, and Sunset lakes are examples. These are the result of stream courses being dammed by drifting sand. This was one of the first areas of the Oregon Coast to be settled and most of the claims were located in a long, narrow corridor about one mile from the coast. Charles Stevens described Clatsop Plains in 1854:

> The country is perhaps the most curious that you ever saw. Just take your map and find Point Adams, at the mouth of this river and run down the coast 20 or thirty miles and you will pass along the western lines of all their claims, here is a high sand ridge, and handsome beach where you can drive a horse and buggy, or a dozen of them together the whole length. About half a mile back of the ridge is another and about one fourth that distance from this is a third ridge which runs the whole length of the Plains, just as straight as the lines on this paper. These ridges are narrow on the top, hardly wide enough for two wagons to pass, and from ten to 30 feet high. Inside this third ridge are a most of their farms.[15]

At the time of settlement, the shoreline was different from the present one. This is a prograding coast—that is, the coast is being built up and advancing to the westward as the Columbia River brings large quantities of sand. At the time of settlement the shoreline was about one-eighth mile farther east at the Necanicum River on the south, about one-half mile in the middle portion of the Plain, and nearly three-fourths of a mile at Point Adams in the north. (Then there was no Clatsop Spit as we know it today. Clatsop Spit was developed partly because of the construction of

the south jetty in the Columbia River.) On the Columbia River itself the shoreline was also quite different. It was low and marshy for the most part, with a number of small streams entering the river, the most significant of which was Skipanon River. To the east of the sandy ridges were the Clatsop Hills, low, rounded, and tree-covered.

Access to Clatsop Plains was mostly by way of the Columbia River; and from the south by trail. Small boats could carry the travelers or settlers across Youngs Bay and into the estuary of Skipanon River, a very short stream that would ordinarily be called a creek. Here, near the present site of Warrenton (see Fig. 2), the settlers landed and traveled overland a short distance to the Plain. The greatest difficulties for land travel were the low, swampy areas, which were flooded in the winter, and the areas of loose sand. The best route followed the long, narrow ridges but, on the whole, travel was comparatively easy, especially north and south. These ridges were old foredunes with just room enough on top for a trail or road. This route paralleled the beach about one mile inland and corresponds very closely to the present Highway 101. It was immediately west of the timbered area where most of the farmsteads were located. Here water was available everywhere in shallow wells, as well as wood from the forest. J. H. Frost, having no spade, dug the first well with an Indian canoe paddle.[16] To the north of Skipanon Landing a trail led to Point Adams with a connecting trail to the beach, but there is little evidence that the beach was used extensively for north-south travel after the dune ridge trail was established.

Settlements were developed on Clatsop Plains very rapidly in the early 1840s. There were at least 20 donation land claims in the narrow belt along the west, and there were also five or more claims on Lewis and Clark River to the east of the hilly section. Clatsop Plains was attractive to the early settlers partly because of the thin vegetation. Most of the area was grassy or covered with low shrubs, so it was by no means difficult to clear land and put it into cultivation. However, the settlers soon found that they had not selected a very good area for agriculture; the sand is too coarse, infertile, and too subject to drought in the summer when the rains are light. Often the settlers after spending a short time on Clatsop Plains moved out, many of them southward to the Tillamook area. Settlers along Lewis and Clark River were more fortunate in that the soils were developed from river flood material and bay deposits, were much more fertile, and also were not so subject to drought.

THE CANNON BEACH–NEHALEM AREA

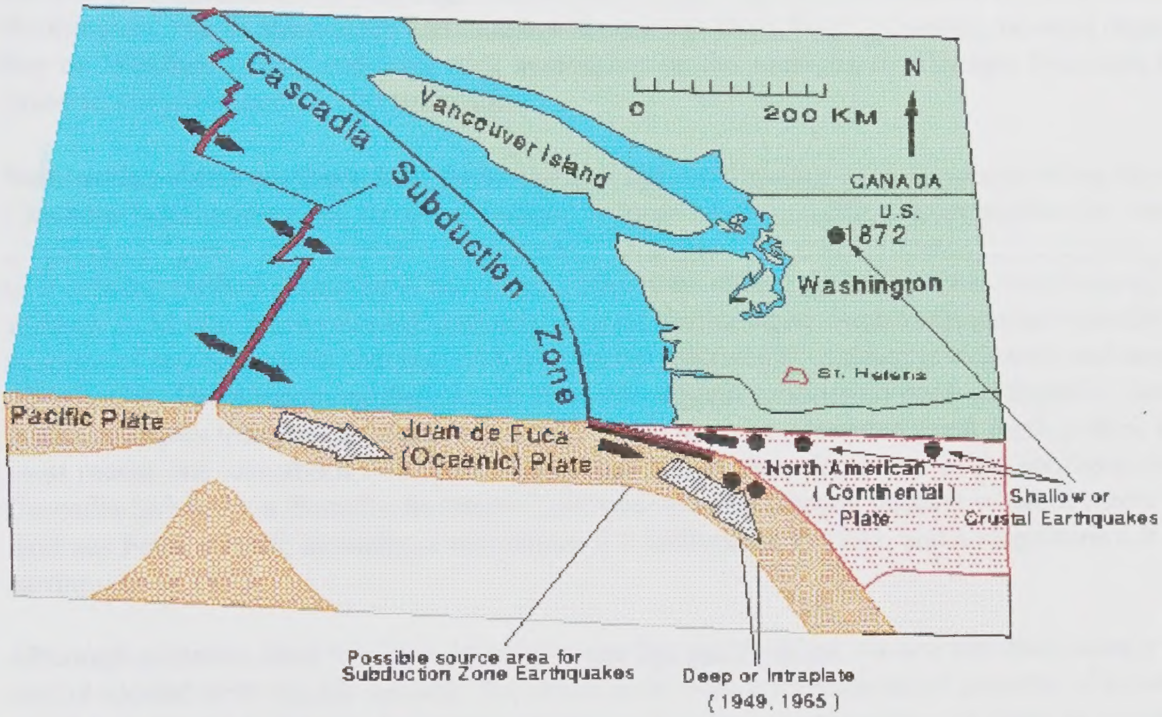
The Cannon Beach-Nehalem Area (Fig. 11) contrasts in many ways with Clatsop Plains. Aside from that part around the lower Necanicum River at Seaside, there is very little land along the coast suitable for cultivation. Also there are several obstacles to travel along the coast, especially Tillamook Head, Cape Falcon, and Neahkahnie Mountain. Tillamook Head is a massive elevation extending out into the sea, underlain by basalt and resistant sediments. Its highest point is 1,200 feet and its western margins consist of very high and steep sea cliffs much subject to landslides. The head is dissected by short canyons, some of which are tributary to Circle Creek on the north; others run directly into the sea. On the south side of the head is the Ecola Park area (Fig. 12), underlain by shales which are especially subject to landslides. From this area small points project out into the ocean, themselves the result of former landslides. These are separated by short beaches, Indian Beach and, to the south of Chapman Point, Crescent Beach.

Captain William Clark crossed Tillamook Head in January, 1806.[17] Previously he had reached Clatsop Plains by canoe from Fort Clatsop to Skipanon Land-

Earthquake Hazards in Washington and Oregon

UNIVERSITY OF WASHINGTON
GEOPHYSICS PROGRAM, SEISMOLOGY LAB AK-50
SEATTLE, WASHINGTON 98195
(206) 543-7010
E-Mail: bill@geophys.washington.edu

Earthquake Source Cross-sectional Map


Cascadia Subduction Zone
Vancouver Island
0
200 KM
N
CANADA
U.S.
1872
Washington
St. Helens
Pacific Plate
Juan de Fuca (Oceanic) Plate
North American (Continental) Plate
Shallow or Crustal Earthquakes
Possible source area for Subduction Zone Earthquakes
Deep or Intraplate (1949, 1965)

The seismology lab at the University of Washington records roughly 1,000 earthquakes per year in Washington and Oregon. Between one and two dozen of these cause enough ground shaking to be felt by residents. Most are in the Puget Sound region, and few cause any damage. However, based on the history of past damaging earthquakes and our understanding of the geologic history of the Pacific Northwest, we are certain that damaging earthquakes (magnitude 6 or greater) will recur in our area, although we have no way to predict whether this is more likely to be today or years from now. A map of selected historic earthquakes shows that while the most damaging events where fairly deep, many moderate sized earthquakes are fairly shallow.

Earthquakes are driven by geologic processes which produce stresses in the earth. In the Pacific Northwest, oceanic crust is being pushed beneath the North American continent along a major boundary parallel to the coast of Washington and Oregon. This boundary, called the "Cascadia Subduction Zone" lies about 50 miles offshore and extends from the middle of Vancouver Island in British Columbia past Washington and Oregon to northern California.

Deep Earthquakes: The two most recent damaging earthquakes in Washington, in 1965 (magnitude 6.5, located between Seattle and Tacoma), and in 1949 (magnitude 7.1, near Olympia), were roughly 40 miles deep and were in the oceanic plate where it lies beneath the continent. Both earthquakes caused serious damage, and were felt as far away as Montana. No aftershocks were felt following them. Other sizable events which were probably deep occurred in 1882, 1909, and 1939.

Shallow earthquakes: The largest historic earthquake in Washington or Oregon occurred in 1872 in the North Cascades. This earthquake had an estimated magnitude of 7.4 and was followed by many aftershocks. It was probably at a depth of 10 miles or less within the continental crust. In 1993, a magnitude 5.6 earthquake in the Willamette Valley caused $28 million in damages (including damage to the Oregon State Capitol in Salem), and a pair of earthquakes near Klamath Falls, OR (magnitudes 5.9 and 6.0) caused two fatalities and $7 million in damages. Many other crustal sources in Washington and Oregon could also produce damaging earthquakes. Recent studies have found geologic evidence for large shallow earthquakes 1,100 years ago within the central Puget Basin. Massive block landslides into Lake Washington, marsh subsidence and tsunami deposits at West Point in Seattle, tsunami deposits at Cultus Bay on Whidbey Island, and large rock avalanches on the southeastern Olympic Peninsula have all been dated to approximately 1,100 years ago.

Subduction Zone earthquakes: Although no large earthquakes have happened along the offshore Cascadia Subduction Zone since our historic records began in 1790, similar subduction zones worldwide do produce "great" earthquakes - magnitude 8 or larger. These occur because the oceanic crust "sticks" as it is being pushed beneath the continent, rather than sliding smoothly. Over hundreds of years, large stresses build which are released suddenly in great earthquakes. Such earthquakes typically have a minute or more of strong ground shaking, and are quickly followed by damaging tsunamis and numerous large aftershocks. The Alaskan earthquake of 1964 was a great subduction zone earthquake. Geologic evidence shows that the Cascadia Subduction Zone has also generated great earthquakes, and that the most recent one was about 300 years ago. Large earthquakes also occur at the southern end of the Cascadia Subduction Zone (in northern California near the Oregon border) where it meets the San Andreas Fault system; including a magnitude 7.1 earthquake in 1992, and a magnitude 6.8 (estimated) earthquake in 1873.

Although scientists have tried for decades to predict earthquakes, no one has discovered a method which can be applied with regular success. For some areas with well-understood patterns of seismicity, it may be possible to forecast decades-long time windows when large earthquakes are likely to occur. However, the Pacific Northwest has only been monitored for a couple of decades; not long enough to allow us to see what patterns, if any, exist here. Seismologists are still trying to understand what types of earthquakes are possible here, and what kind of shaking we will experience from future earthquakes (depending on the earthquake location and size, and the site geology and topography). Earthquake hazards can be reduced by advance preparation; such as coordinating emergency communications and activities across jurisdictional lines, preparing personal emergency plans, and considering seismic hazards in land use plans, building codes, and planning for medical, utility, and emergency facilities.

The Federal Emergency Management Agency (FEMA) has a set of documents about earthquake hazard prepardness including what to do before, during and after an earthquake. For more detailed information about earthquakes and earthquake hazards in the Pacific Northwest, there is a list of resources, the best of which is Information Circular 85 "Washington State Earthquake Hazards" available for $1.00 (postage and handling) from the Washington State Dept. of Natural Resources, POB 47007, Olympia, WA 98504-7007

Back to:... **UW GEOPHYSICS PROGRAM** ..... **SEISMOLOGY INFO** ..... **PNW**

EARTHQUAKES

University of Washington Geophysics Program, Box 351650 Seattle, WA, 98195-3650
This is file /SEIS/PNSN/INFO_GENERAL/eqhazards.html; modified 10/11/96 - If you see any problems
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Reference: (Mooney, 1928)

Indian Tribes of Wash, Or., Idaho.
John Reed Swanton
Ye Galleon Press. Fairfield, Wa
1979.

Clatsop - a native word meaning "dried salmon".
location: centered near Cape Adams (near Hammond - Warrenton) as far E as Tongue point and S to Tillamook Head.
Villages: Neahkeluk, at Point Adams
Niakewankih S of Point Adams at mouth of Ohanna Creek
Neahkstowt, near Hammond.
p.61 Population: 300 in 1780 - 1806 (Lewis & Clark)

Please see additional information on incidences of nasal stinging and burning, references and full prescribing information on back pages.

Indians sent to Grande Ronde Res in 1875.

VP-067/14510109

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OREGON GEOLOGIC TRIP GUIDES AND RECREATIONAL GEOLOGY ARTICLES

Articles published in the Department's monthly magazine, *The Ore Bin* (1939-1978) and *Oregon Geology* (1979-April, 1988), are available for $1.00 per copy. Articles published in *Oregon Geology* (May/June 1988-November 1994) are available for $2.00 per copy. Articles published in *Oregon Geology* (January 1995-present) are avaiable for $3.00 per copy.

State Parks

Humbug Mountain State Park area [Curry County] (March 1961)	1.00
Cape Sebastian State Park [Curry County] (August 1961)	1.00
Ecola State Park landslide area [Clatsop County] (September 1961)	1.00
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Cape Lookout State Park near Tillamook (May 1967)	1.00
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Trip guide along northern Oregon coast: evidence of subduction zone seismicity (Sept. 1993)	2.00

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Geology markers along Oregon highways (October 1971)	1.00
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Guide to northern Klamath Mtns. (March 1992)	2.00
Natural hazards of the Pacific Northwest, past, present, future-a field trip guide for western Oregon and Mt.St. Helens(July 1992)	2.00
Field guide to the geology and paleontology of pre-tertiary volcanic arc and melange rocks, Grindstone, Izee, and Baker terranes, east-central Oregon(November 1992)	2.00
Field trip guide to paleoseismicity on north Oregon coast (September 1993)	2.00
Beyond the channeled scabland, parts 1, 2, and 3 (May, July, and September 1995)	9.00

Books of Field Trips Available from the Department

Geologic field trips in western Oregon and southwestern Washington (Bulletin 101, price $10.00)-- contains:

- Volcanic and volcanistic rocks on the east flank of the central Cascade Range to the Deschutes River (field trip itinerary)
- Paleogene stratigraphy and structure along the Klamath borderland (road log)
- Geology of the west-central part of the Oregon Coast Range (road log)
- Geologic summary for a field guide through the north-central Klamath Mountains
- Geologic field trip guide for the Cenozoic stratigraphy and late Eocene paleocology of southwestern Washington (road log)
- Marys Peak field trip: Structure of the eastern flank of the central Coast Range, Oregon (road log)
- Guide to the geology of the upper Clackamas and North Santiam Rivers area, northern Oregon Cascade Range (field trip stops)
- Beach processes and erosion problems on the Oregon coast (field trip stops)
- Field trip road log for the Cenozoic stratigraphy of Coos Bay and Cape Blanco, southwestern Oregon (road log)
- Field trip guide: Geomorphology and hydrology in the H.J. Andrews Experimental Forest (field trip stops)

Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California (U.S. Geological Survey Circular 838, available free in Portland, office, one to a customer, no mail orders.)--contains:

- Trip between Lewiston, Idaho, and Kimberly, Oregon, with emphasis on the Columbia River Basalt Group (guide + road log)
- Trip between Kimberly and Bend, Oregon, with emphasis on the John Day Formation (guide + road log)
- Central High Cascade roadside geology) Guide + road log for Bend-Sisters-McKenzie Pass-Santiam Pass)
- Guide to Newberry Volcano, Oregon (guide + road log)
- High Lava Plains, Brothers fault zone to Harney basin, Oregon (guide + road log)
- Trip to maar volcanos of the Fort Rock-Christmas Lake Valley basin, Oregon (road log)
- Trip to Medicine Lake Highland, California (road log + 5 articles)

How to obtain these publications

All publications are available at the The Nature of Northwest Information Center, Suite 177, 800 NE Oregon Street #5, Portland, OR 97232. Allow approximately 4 weeks for delivery. Payment must accompany orders under $50. Foreign orders: Please remit in US dollars. All sales are final.

In the case of *Ore Bin/Oregon Geology* issues, photocopies may have to be substituted for out-of-print issues.

USGS Circular 838 may also be requested from the Public Inquiries Office, U.S. Geological Survey, 678 U.S. Courthouse, West 920 Riverside Avenue, Spokane, WA 99201, phone (509) 353-2524, or from the U.S. Geological Survey, Books and Open-File Reports, Federal Center Building 41, Box 25425, Denver, CO 80225

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RIVERS - COLUMBIA RIVER
MOUTH, BAR, JETTY

History of the mouth of the Columbia River

GB HegardT, Eng.
Port chamber of commerce 1913

SOURCE: THE Colum
Murray Morgan
Superior Publ. Co.
Seattle WA 1949

~~1885 - Built South jetty~~

while on the ship "William and Ann"
David Douglas, the botanist, in 1825
claimed the Col River Bar (CRB) as a 1,000
times worse than Cape Horn. Four years
later that same ship was broken on the
Clatsop Spit on the Col S. side of the
River, drowning everyone on board.

In 1841 The Wilkes Expedition had a
vessel named "Peacock"

The signature of a winner

that went aground on the north spit.
No one survived this wreck. The spit
was named peacock, after the
sunken war sloop'.

By the time of the Cal. Gold Rush
the Columbia had the reputation
of the Graveyard of the Pacific. As
navigators became acquainted with
its capriciousness, pilots and tugboats
~~were a common sight~~ helped navigate
the river. By 1885, the government
sent engineer to design and build,
the South jetty, throwing the main
force of the river to the middle. By 1917
the north jetty was completed which
prevented wrecks, but there is a continuous
danger ~~in the~~ crossing the bar to this day.

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979.12 Columbia River
M823c Morgan, Murray
1940

917.91 Clatsop co.
F312hi Feldman, M.
1973 HISTORICAL SITES

979.123.
O66c
Lynda Lesowski - Hist. Coquille River Co
1920
1979

The signature of a winner

Ref

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

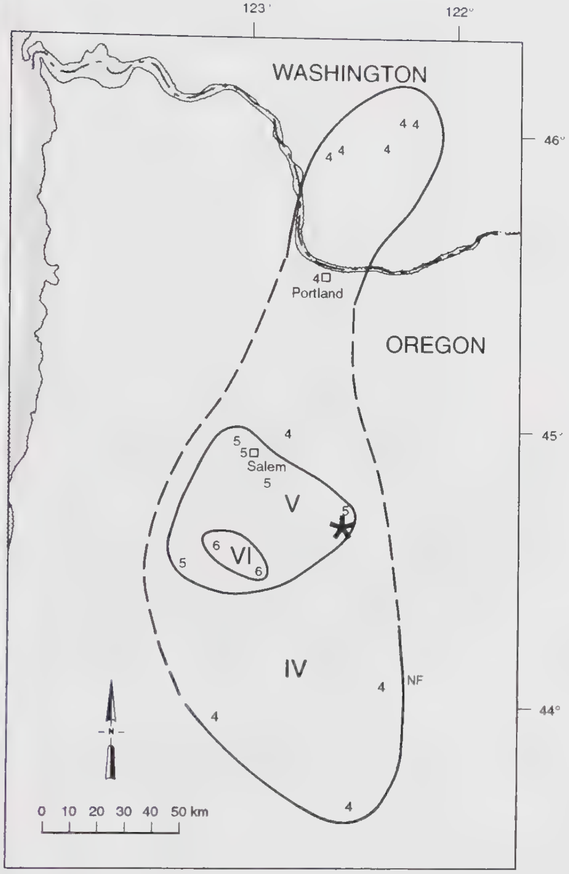
VOLUME 55, NUMBER 5

SEPTEMBER 1993

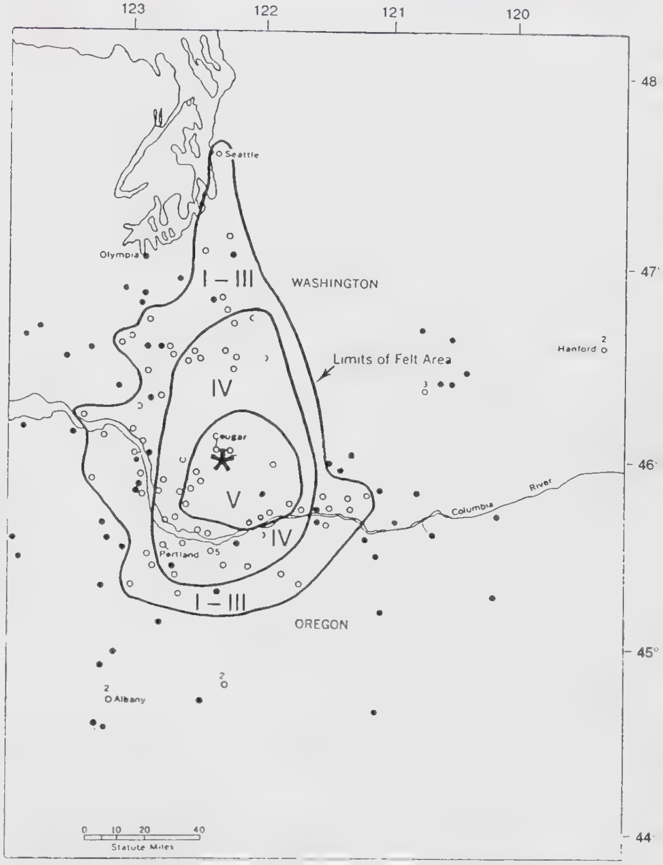
IN THIS ISSUE:

Historical earthquakes in and around Portland

Field trip guide along northern Oregon coast: Evidence of subduction zone seismicity

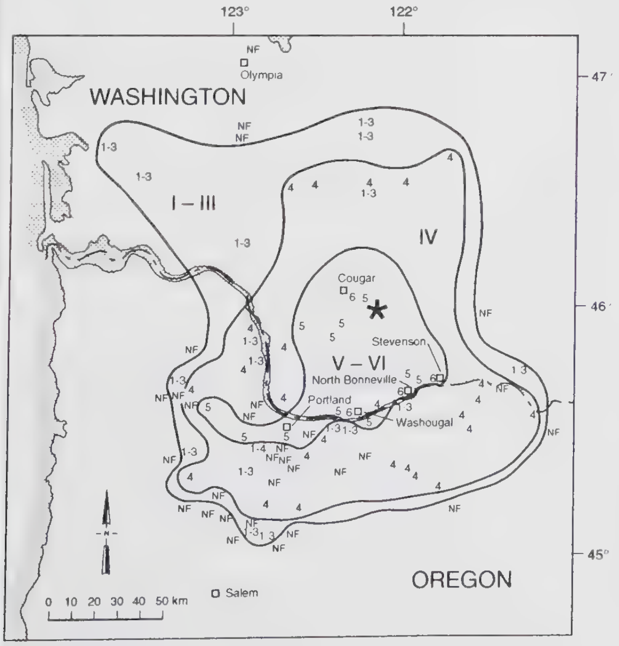


18 August 1961 M_L 4½

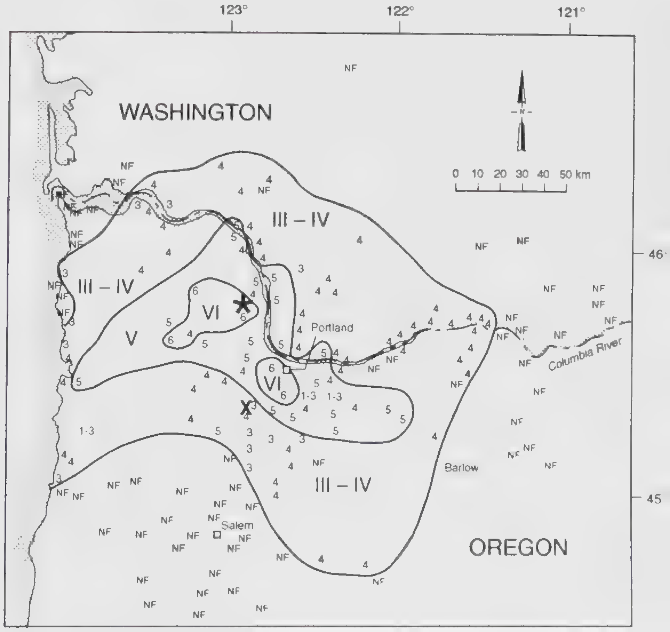


Source: Lander and Cloud (1963)

15 September 1961 M_L 4.8



17 September 1961 M_L 5.1



6 November 1961 M_D 5.1

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 55, NUMBER 5 **SEPTEMBER 1993**

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. If manuscript was prepared on common word-processing equipment (IBM compatible or Macintosh), a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, 3.5-inch high-density diskette only). Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover illustration

Isoseismal maps for significant earthquakes in 1961 near Portland. "X" indicates additional epicentral locations as described in text. Related article about historical earthquakes in and around Portland begins on page 116.

OIL AND GAS NEWS

Drilling continues at Mist Gas Field

At the Mist Gas Field in Columbia County, Nahama and Weagant Energy Company of Bakersfield, California, continues the multiple-well drilling program that began during May. Longview Fibre 12A-33-75 (TD 2,475 ft) was completed as a successful gas well; Longview Fibre 12B-35-65 (TD 3,727 ft) is currently suspended; CFW 41-35-75 (TD 3,331 ft), Adams 31-34-75 RD (TD 3,419 ft), and CC 41-36-75 (TD 1,792 ft) were plugged and abandoned; CC 22B-19-65 is currently suspended at a total depth of 2,940 ft; and at LF 31-36-65, drilling operations are underway.

NWPA symposium approaching fast

Registration materials are still available for the Northwest Petroleum Association (NWPA) 10th annual symposium, which will be held September 26-28, 1993, at the Inn of the Seventh Mountain in Bend, Oregon. The symposium will include a field trip to the Newberry National Volcanic Monument. For further information, contact the NWPA, PO Box 6679, Portland, OR 97228-6679.

Mist Gas Field celebrated

During this summer, the Mist Gas Field, which was discovered in 1979 and has currently 17 productive wells and an underground natural gas storage facility, reached $100 million in revenues from natural-gas production. In recognition of this milestone, the Oregon Department of Geology and Mineral Industries, Northwest Natural Gas Company, Oregon Natural Gas Development Corporation, and Nahama and Weagant Energy Company held a celebration on September 11 at the field. The field is a successful endeavor between private industry, government, and public organizations, in which landowner rights and the environment are protected, while the natural gas generates tax and royalty revenues and provides employment and other direct benefits for residents of Columbia County.

Revised *Mist Gas Field Report* released

The *Mist Gas Field Report* is now available in its annually updated version. See the more detailed announcement on page 114 in this issue of *Oregon Geology*.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
488	Nahama and Weagant Adams 14-31-74 36-009-00310	SE¼ sec. 31 T. 7 N., R. 4 W. Columbia County	Permit issued; 2,700.
489	Nahama and Weagant HNR 42-27-64 36-009-00311	NE¼ sec. 27 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,500.
490	Nahama and Weagant HNR 24-22-64 36-009-00312	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,700.
491	Nahama and Weagant HNR 31-21-64 36-009-00313	NE¼ sec. 21 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,100.
492	Nahama and Weagant CFW 23-33-74 36-009-00314	NW¼ sec. 33 T. 7 N., R. 4 W. Columbia County	Permit issued; 1,700.
493	Nahama and Weagant CC 24-19-65 36-009-00315	SW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Application; 3,000.

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Field trip guide to Cascadia paleoseismic evidence along the northern Oregon coast: Evidence of subduction zone seismicity in the central Cascadia margin

Revised from Friends of the Pleistocene Field Trip Guide, 1993

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SUMMARY

Broad pocket beaches, low marine terraces, and numerous small estuaries are characteristic features of the northern Oregon coast, the middle part of the Cascadia coastline that extends from British Columbia to northern California. Like the middle child, the northern Oregon coast provides the link between the northern and southern ends of the Cascadia margin. Perhaps less dramatic in relief but not in beauty, this central Cascadia coastline differs significantly from the jagged coastlines of northern Washington and southern Oregon/northern California. The apparent geologic quiescence of the northern Oregon coast does not reflect the catastrophic earthquakes that have struck the region in recent prehistoric time.

On this field trip, we explore the northern half of the Oregon coastline for geologic evidence of subduction zone seismicity. Such evidence includes multiple events of abrupt coastal subsidence, tsunami inundation, and shaking-induced liquefaction of unconsolidated sediments. The earthquake evidence is recorded in late Holocene tidal-basin deposits (300–5,000 years old) and in uplifted marine terrace deposits of late Pleistocene age (80,000–120,000 years old). A total of 16 field localities showing evidence of earthquake-induced subsidence, tsunami generation, liquefaction, and/or debris flows are discussed in this field trip guide (Figure 1).

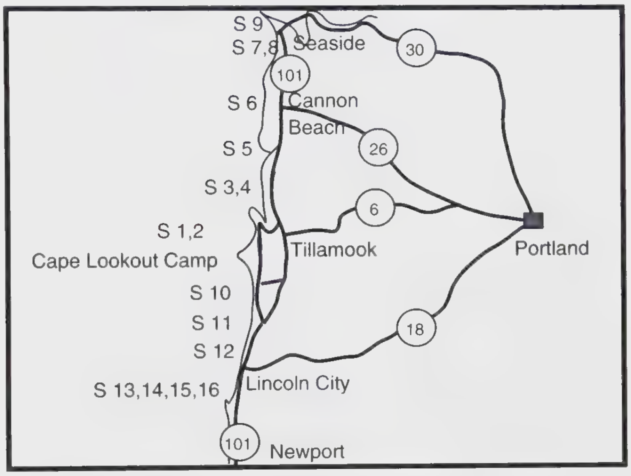

Figure 1. Regional highway map with field trip stops (S 1–16).

INTRODUCTION

The potential for great earthquakes in the Cascadia Subduction Zone (CSZ) (Figure 2), where the Juan de Fuca Plate is being subducted under the North American Plate, is one of the most controversial topics in Quaternary geology of the Pacific Northwest. In the last dozen years, expert opinions on the nature of seismicity along this margin have ranged from terminated subduction to aseismic subduction to the potential for great (M_W 9) subduction zone earthquakes (Heaton and Kanamori, 1984). Late Quaternary deposits of the central CSZ are reported to show evidence of episodic coastal subsidence and tsunami deposition (Figure 3) (Atwater, 1987; Darienzo and Peterson, 1990), coseismic sediment liquefaction (Peterson and Madin, 1992), and coseismic debris flows (Darienzo, 1991; Gallaway and others, 1992). However, the reported evidence of episodic coastal subsidence and associated tsunami deposition as been interpreted by some to possibly represent spit breaches, storm surges, or other aseismic mechanisms. In this field trip guide, we discuss field sites that discriminate between seismic and aseismic mechanisms causing episodic marsh burial. However, these sites must be viewed within the larger neotectonic context of the central Cascadia margin to evaluate their relevance to the paleoseismicity debate.

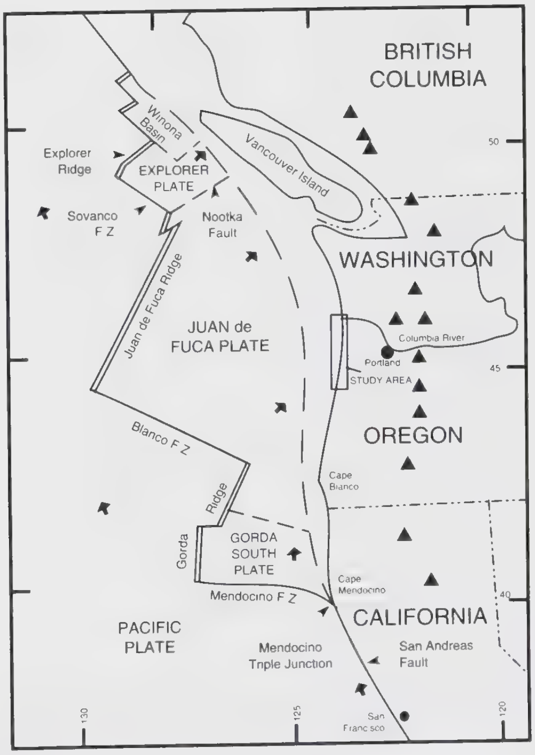

Figure 2. Tectonic framework of the Cascadia Margin and location of field trip area (plate motions indicated by bold arrows).

REGIONAL NEOTECTONIC FRAMEWORK

The central Cascadia margin, both offshore and onshore, is now known to be riddled with faults and folds in the upper North American Plate (Figure 4). Some faults possibly extend downward to the plate interface or even into the lower Juan de Fuca Plate (Goldfinger and others, 1992; Vern Kulm, Oregon State University, personal communication, 1993). Are these faults active, and if so,

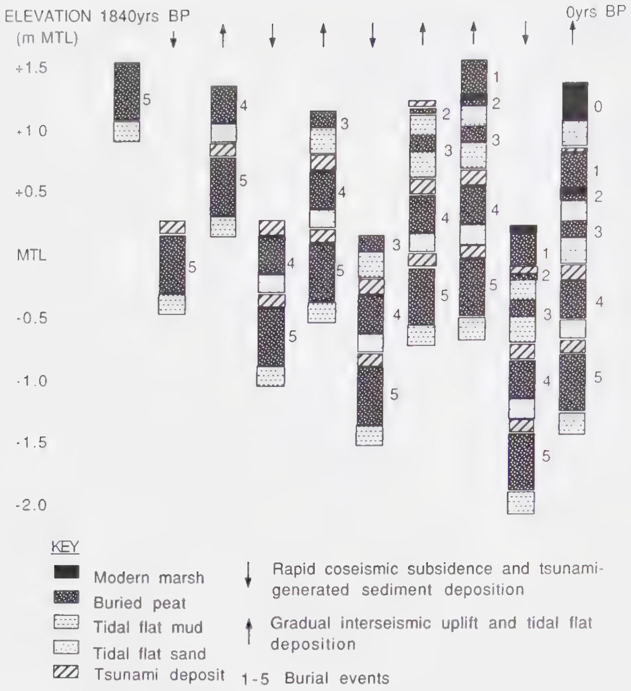

Figure 3. Stratigraphic stacking model of rapid coseismic subsidence followed by gradual sedimentation and post-seismic tectonic rebound that produced the upper 2.5 m of the stratigraphic record at Netarts Bay. The amount of subsidence is determined from estimates of modern and paleoenvironmental tidal elevations. After Darienzo and Peterson (1990).

what accounts for their combined lack of historic seismicity? How have these folds and faults affected the coastal stratigraphic record? The northern Oregon coastal terraces (late Pleistocene in age) show relatively less vertical deformation than do corresponding terraces from the southern and northern ends of the margin (Figure 5). We ascribe the larger rates of coastal inelastic deformation (faults and folds) in the southern Cascadia margin to its being closer to the deformation front, i.e., the leading edge of the North American Plate (Peterson and others, 1991). The larger rates of coastal inelastic deformation of the Cascadia margin in northern Washington might be due to its proximity to the margin bend, i.e., the bulge in the downgoing slab at the Olympic Pensinsula (Figure 2). A compensatory bulge in the downgoing slab at the margin bend might increase the width of the locked zone and its associated upper-plate deformation in the Olympic Peninsula (Crosson and Owens, 1987).

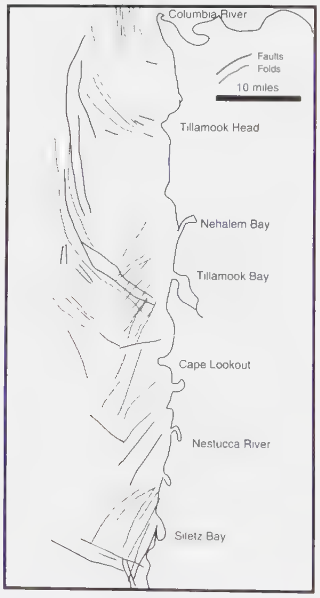

Figure 4. Coastal section of the offshore neotectonic map. Redrawn from Goldfinger and others (1992).

In addition to the inelastic deformation, there is the predicted component of cyclic elastic deformation associated with episodic dislocation of a strongly coupled megathrust (Heaton and Kanamori, 1984). Alternating conditions of aseismic coastal uplift and coseismic coastal subsidence are predicted for coastlines landward of a zero isobase of upper plate flexure (Figure 6). Preliminary maps of episodic coastal subsidence or continuous subsidence have been established from buried marsh records in late Holocene wetland deposits of the central Oregon coast (Briggs and Peterson, 1992). The initial results of this mapping suggest that the central Cascadia coastline converges with the predicted zero isobase of elastic flexure in central Oregon (Figure 7). The apparent coincidence of both diminished terrace deformation and the zero isobase of elastic deformation in the central Oregon coast might denote the landward limit of the locked zone (Peterson and Briggs, 1992). All of the marsh settings observed in this field trip (northern Oregon coast) should fall in the realm of elastic coseismic subsidence, if the assumptions above are valid.

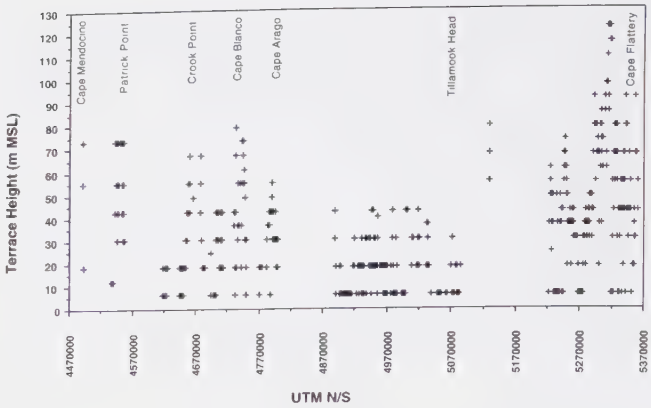

Figure 5. Plot of lowest-terrace surface elevation versus distance (UTM) along the Cascadia margin. From Peterson and others (1991).

Finally, direct evidence of earthquake rupture length, which is related to earthquake magnitude, has proven to be elusive in the central Cascadia margin. Because of the relatively poor precision

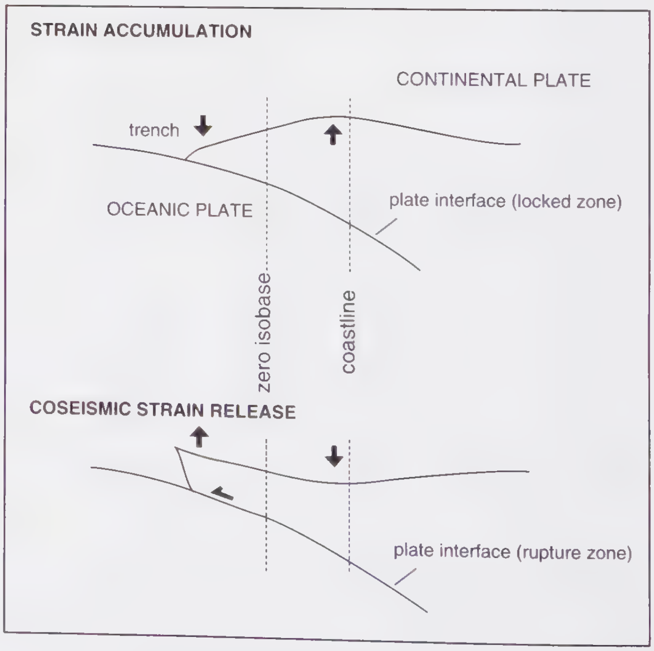

Figure 6. Simplified cross section of zero isobase, plate subduction, and deformation cycles. From Darienzo (1991).

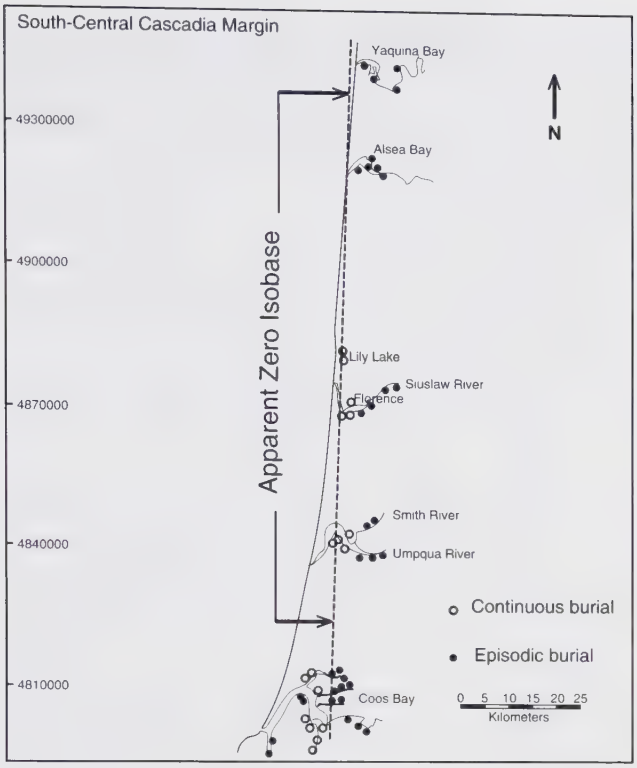

Figure 7. Map of core sites showing episodic burial (solid circles) and continuous burial (open circles) in central Oregon (unpublished map relating to Briggs and Peterson, 1992). Continuous burial cores are thought to lie on zero-isobase of upper plate flexure (see Figure 6).

of radiocarbon dating, it has not been possible to use that method to prove that the entire coast subsided at the same time in one catastrophic earthquake. Dendrochronology (tree ring dating) has successfully constrained the age of the last subsidence event(s) (approximately 300 years ago) in coastal wetlands of southern Washington (Yamaguchi and others, 1989).

What is required to test the model that large earthquakes affected many areas along the coast simultaneously (event synchroneity) is a unique stratigraphic record of coastal subsidence and corresponding tsunami inundation that can tie widely separated bays to distinct regional events (Figure 8) (Peterson and Darienzo, 1992). Such a record might exist in the northern Oregon coast, where the last five Cascadia Subduction Zone (CSZ) subsidence events apparently establish a unique regional sequence (Figure 9) (Darienzo, 1991). This sequence includes the following events:

- Event 1. Subsidence + tsunami at approximately 300 calendar years before present (Cal. Yr. BP).
- Event 2. Northward-decreasing subsidence + tsunami at approximately 800±200 radiocarbon years before present (RCYBP).
- Event 3. Subsidence + no tsunami (possible exception at Seaside) at approximately 1,100±200 RCYBP.
- Events 4 and 5. Each with subsidence + tsunami, both roughly in the range of 1,500–1,800 RCYBP.

If confirmed, this central Cascadia earthquake sequence might ultimately provide a link to bridge the paleoseismic records of the southern and northern regions of the Cascadia Subduction Zone.

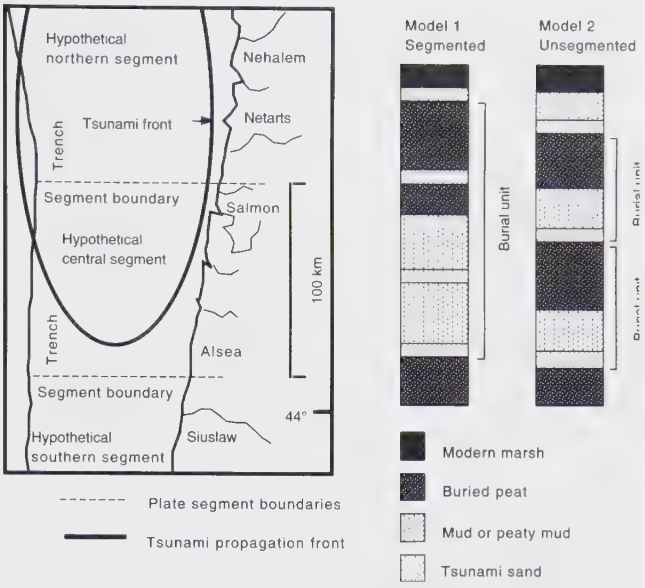

Figure 8. Two models of marsh development and tsunami deposition used to discriminate rupture segments in the northern Oregon coast. One-to-one correspondence between buried peat (coastal subsidence) and tsunami deposition at adjacent bays indicates event synchroneity between bays. From Peterson and Darienzo (1992).

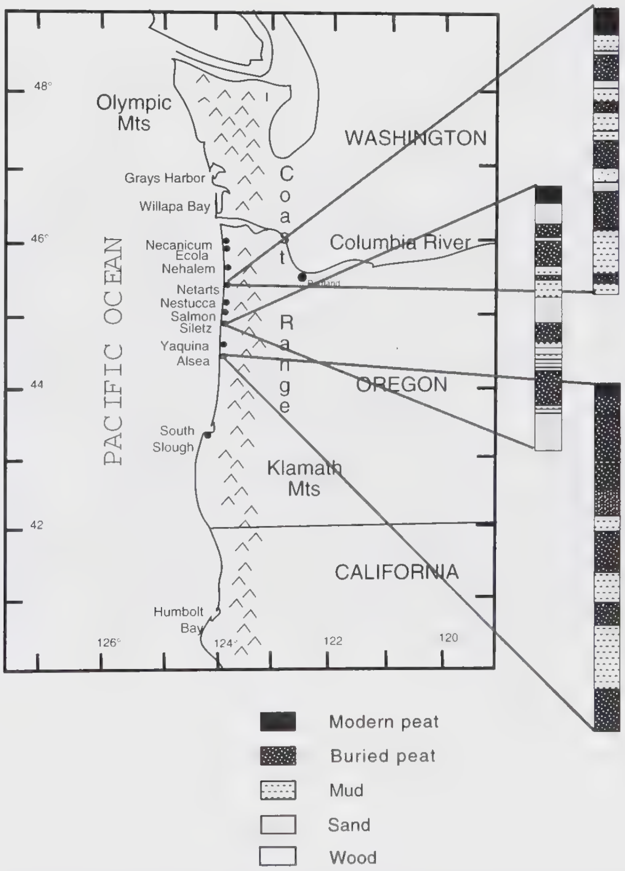

Figure 9. Representative stratigraphy of three sites (Netarts Bay, Siletz Bay, and Alsea River) on the northern Oregon coast. These sites record five coseismically buried peats (indicated by numbers next to stratigraphic column) in approximately the last 2,000 years, suggesting regional synchroneity of the events.

SITE DESCRIPTIONS

Warning: Oregon beaches are renowned for sneaker waves. While viewing these stops, please keep an eye on the ocean and your companions if you venture near the surf zone. Also, to minimize impact on rural coastal communities, park well off the roadside and keep to public access paths. Finally, Stops 1, 2, 8, 11, and 14 can be fully viewed only at low tide. Consult tide tables and plan your trip accordingly.

Stop 1. Netarts marsh, Netarts Bay

Location (Figure 10): Netarts Road about half a mile north of the Cape Lookout campground. Park on the side of the roadway. Walk out onto the bay marsh at a road culvert, about 150 ft north of the debris-flow chute. The modern debris-flow deposits extend out on the marsh about 150 ft west of the road culvert. Continue another 150 ft west, beyond the debris flow fan, to the cutbank of a small tidal channel to view the prehistoric marsh stratigraphy. **Requires low tide to see all outcrops.**

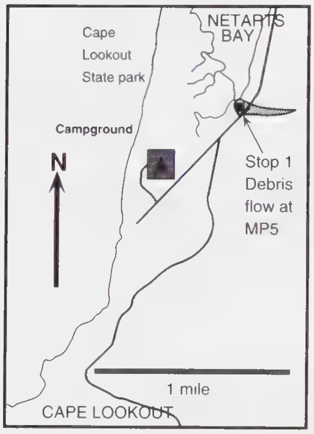

Figure 10. Location of Stop 1. MP = mile post.

Features: Type section of episodic coastal subsidence and tsunami deposition in the northern Oregon coast. Also, rapid recolonization of modern (aseismic) debris flow on marsh, confirming submergence mechanism of prehistoric peat burial.

Site description: Netarts Bay is a shallow lagoon bounded by Cape Meares and Cape Lookout (two basaltic headlands), a sand spit, and the Coast Range (Figures 1 and 11). We consider the Netarts Bay marsh stratigraphy to be the type section for paleoseismological evidence of Cascadia earthquakes in the last 3,000 years along the northern Oregon coast (Figure 12) (Darienzo, 1991). Buried peats are overlain by distinct tsunami sands and/or barren to rooted tidal flat muds. The development of the marsh stratigraphy over the last couple of thousand years, including the last five coseismic burial events, is a combination of tectonic and eustatic sea-level rise processes (Figure 3). The record of alternating uplift and coseismic subsidence (1–1.5 m [3–5 ft] of vertical deformation) is preserved by eustatic sea-level rise and sedimentation in the protected bay wetlands.

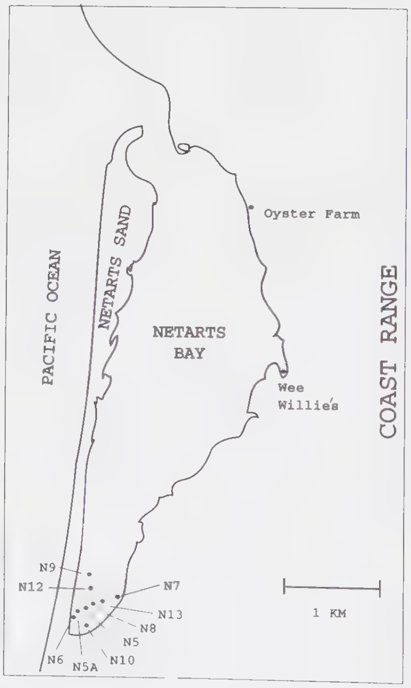

Figure 11. Sketch map of Netarts Bay showing core site locations.

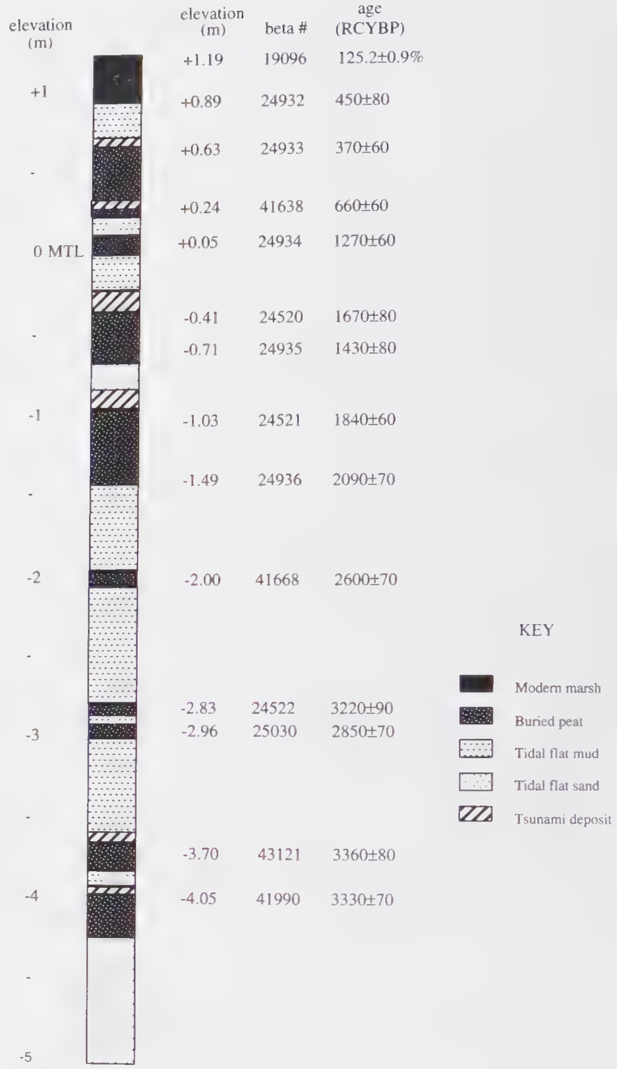

Figure 12. Generalized stratigraphy of buried peats and tsunami deposits with corresponding radiocarbon ages in Netarts Bay. Beta number is radiocarbon laboratory sample number.

In December 1990, a small debris flow (4 x 10^3 m^3 [141 x 10^3 ft^3] at the source) covered a 5 x 10^3 m^2 (54 x 10^3 ft^2) area of modern, transitional salt marsh (average elevation + 1.3 m [4 ft] mean sea level [MSL]) in the southeast margin of Netarts Bay (C.D. Peterson and others, unpublished data, 1991). The debris-flow sediments overlying the marsh include gravel, sand, and mud (1–50 cm [0.4–20 in.] in thickness) that fanned out onto the preexisting marsh surface (Figure 13). Salt marsh plants, dominated by *Deschampsia caespitosa*, rapidly recolonized the debris-flow deposit, completing dense vegetative cover within one year. The resulting marsh burial deposit is characterized by lateral discontinuity, chaotic internal structure, very poorly sorted sediments, and abundant plant shoots. In the absence of relative sea-level rise, this catastrophic burial process was unable to terminate marsh growth or yield any burial sequences characteristic of older (prehistoric) subsidence events at this site.

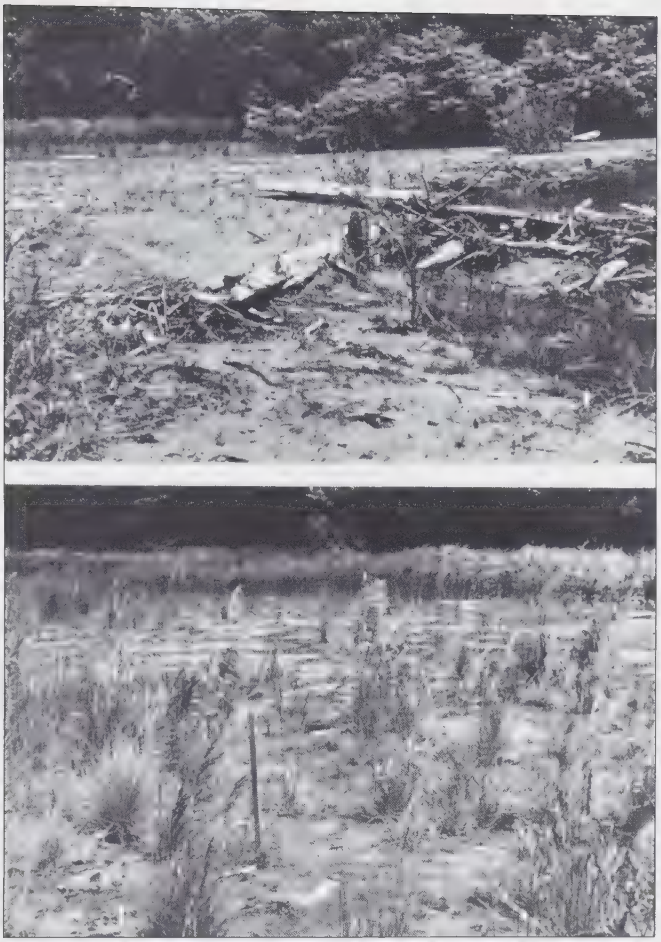

Figure 13. Photographs of debris flow on marsh at Stop 1, both taken six months after the marsh burial. Dense vegetative cover was complete within 12 months after burial by the debris flow.

Stop 2. Wee Willie's, Netarts Bay

Location (Figure 14): Netarts Road 3¼ mi north of Cape Lookout State Park campground entrance. Park near Wee Willie Restaurant. Walk out onto the small marsh and view buried peats/tree roots in tidal creek cutbanks. Continue southwest around a bay terrace point, about 300 ft from the parking lot, to the Pleistocene terrace deposits that front the bay shoreline. Continue about half a mile south along the exposed terrace deposits. **Requires low tide.**

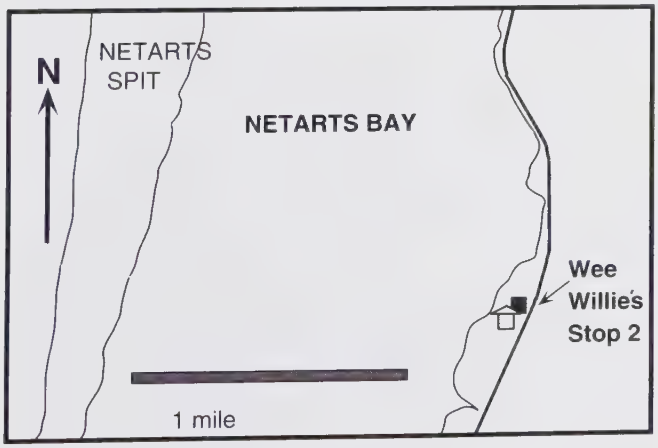

Figure 14. Location of Stop 2.

Features: Late Holocene record of coseismically buried peats and tsunami-deposited sands in marsh cores and cutbanks (Figure 15). Late Pleistocene analogs of abruptly buried peats in adjacent bay terrace deposits.

Site description: At the marsh at Wee Willie's (Figures 11 and 14), coseismically buried peats are visible in cutbanks and deeper cores. Protruding tree roots in the buried peats are indicators of forested wetlands and demonstrate past episodes of tectonic uplift above the reach of tidal range sedimentation. The prehistoric records of the last three CSZ subsidence events can be seen in the tidal creek cutbanks including Event 1 (buried peat and tsunami sand), Event 2 (tsunami sand in rooted mud), and Event 3 (buried peat but no tsunami deposit). At least six coseismic burial events have been documented in deeper cores of the site at Wee Willie's. The oldest dated peat is about 2,600 radiocarbon years before present (RCYBP). Sharp contacts between peats and overlying tsunami sands or bay muds correspond to equally abrupt changes from (1) fresh-water diatoms to brackish-water diatoms and/or (2) fossil *Juncus* rhizomes (high marsh) to *Triglochin* rhizomes (low marsh to colonizing tidal flat species). All of these paleotidal indicators point to episodic events of rapid marsh submergence. The lack of such records in some central Oregon marsh sites (Briggs and Peterson, 1992) rules out eustatic or regional sea-level changes as the mechanism responsible for the episodic submergence. The marsh burial events recorded in Netarts and other northern Oregon bays are the result of tectonic subsidence.

Late Pleistocene analogs to the buried marshes at Wee Willie's are found at many locations in marine terrace deposits of the central Oregon coast (Mulder, 1992). Perhaps the best exposed buried Pleistocene peats are those that occur in the youngest uplifted terrace deposits, assumed to be the Whisky Run terrace at about 80,000 years old (80 ka), that rim Netarts Bay (Figure 16). At least 11 subsidence events are recorded in continuous drill cores and exposed bay cliffs at this site (Figure 17). These sections are thought to represent about a 5,000-year period (maximum) of

Figure 15. Photograph of Friends of the Pleistocene field trip participants viewing cutbanks in small tidal creek of the marsh at Wee Willie's.

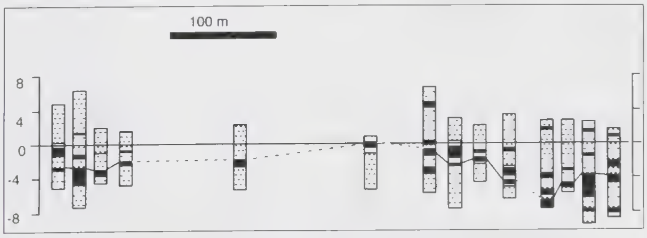

Figure 16. Cross section of buried peat horizons in late Pleistocene bay terrace deposits. From Mulder (1992).

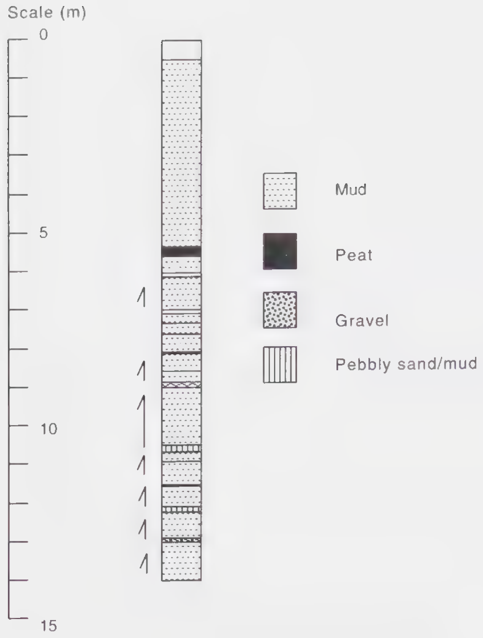

Figure 17. Core log from a drill site, located 1,600 ft (0.5 km) southeast of Wee Willie Restaurant, in late Pleistocene marine terraces. Black lines show buried peats, and arrows show grain-size fining-up trends associated with interseismic emergence. From Mulder (1992).

deposition, yielding an approximate average recurrence interval of not more than 500 years (Mulder, 1992). The terrace deposits also show subtle signs of liquefaction including muddy flow bands and small vertical dikes but no large-scale warping (folds) or vertical offsets (faults). The lack of substantial inelastic deformation of the terrace deposits here argues against the episodic subsidence originating from local faults (Figure 4). By contrast, local faults and folds are thought to dominate the coastal subsidence record in southern Oregon (Peterson and Briggs, 1992) and northernmost California (Clarke and Carver, 1991).

Stop 3. Cape Meares overlook

Location (Figure 18): Three Capes Highway, 12 mi east of Cape Meares. Park on the side of the roadway where the Tillamook Bay and spit can be viewed (Figure 19).

Features: Overview of Tillamook Bay to the north, including fringing bay marshes and major historic spit breach. Large landslide area is visible to the west, on the north side of Cape Meares.

Site description: Tillamook Bay has experienced some significant changes in historic time, including rapid sedimentation following the Tillamook burn, extensive dike construction for pasturage, and a major spit breach from 1952 to 1956 (Glenn, 1978). However, these historic changes are small by comparison to the late Holocene subsidence events that flooded all of the tidal marshes surrounding the bay. Evidence of episodic events of abrupt sea-level rise (1–2 m [3–6 ft] subsidence) is recorded by bay muds overlying supratidal peats in wetland deposits at the north, south, and west ends of the bay (Figure 20). There are also late Pleistocene buried peats exposed in sea-cliff terrace deposits just north of Cape Meares (see Stop 4 below). As with Netarts Bay, the late Pleistocene Tillamook estuary extended much farther seaward than does the present bay.

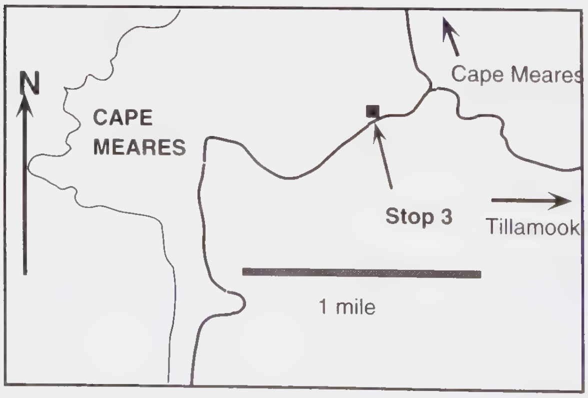

Figure 18. Location of Stop 3.

Figure 19. Overview of Tillamook Bay, view to the north, showing bay spit.

The major historic spit breach (1952) at the south end of the Tillamook Bay spit (Figure 20) left no geologic evidence of submergence or catastrophic flooding in adjacent marshes. The lack of marsh response to this historic spit breach is significant in view of the size of the breach prior to artificial closure by the U.S. Army Corps of Engineers in 1956. Based on these observations and similar ones in Alsea Bay (Peterson and Darienzo, 1992), we conclude that prehistoric spit breaches are unlikely candidates for the mechanism(s) of episodic marsh termination and burial recorded in the larger Cascadia tidal basins.

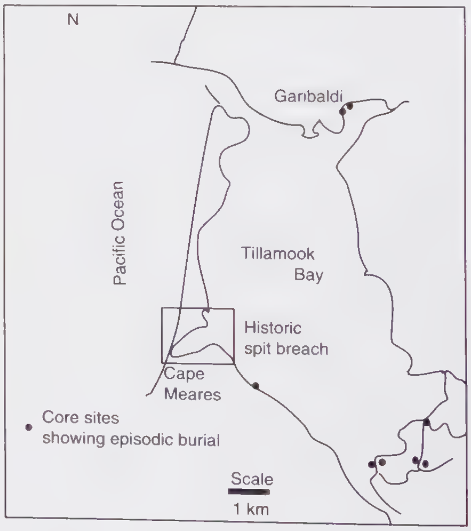

Figure 20. Map of Tillamook Bay, including marsh core sites recording prehistoric subsidence events. Core sites at Garibaldi show thin tsunami deposits over prehistoric buried peats. The historic breach of the southern end of the Tillamook Bay spit is shown (box). Adjacent marsh sites show no evidence of submergence from the spit breach.

Stop 4. Cape Meares beach

Location (Figure 21): Beach access in the Cape Meares village. Park off the roadway, and please do not block the residents' driveways. Walk out onto the beach and head south ⅓ to 1 mi along the sea cliffs.

Features: Late Pleistocene peats, liquefaction, and colluvium in marine (bay) terrace deposits (Figure 22).

Site description: At least three buried peat horizons can be traced in late Pleistocene estuarine deposits in the sea cliffs south of the town of Cape Meares. The buried peats generally show sharp upper contacts with bay muds, indicating abrupt subsidence (Mulder, 1992). Small clastic dikes and abundant muddy-flow features demonstrate sediment liquefaction. Are these liquefaction features of coseismic origin, or were they produced by debris-flow loading? Toward the southern end of the exposed Pleistocene section, the bay deposits are buried under colluvium derived from the Cape Meares ridge.

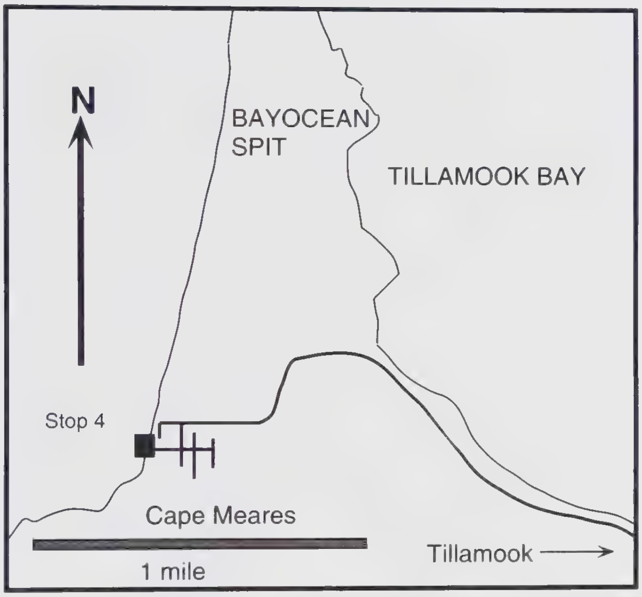

Figure 21. Location of Stop 4.

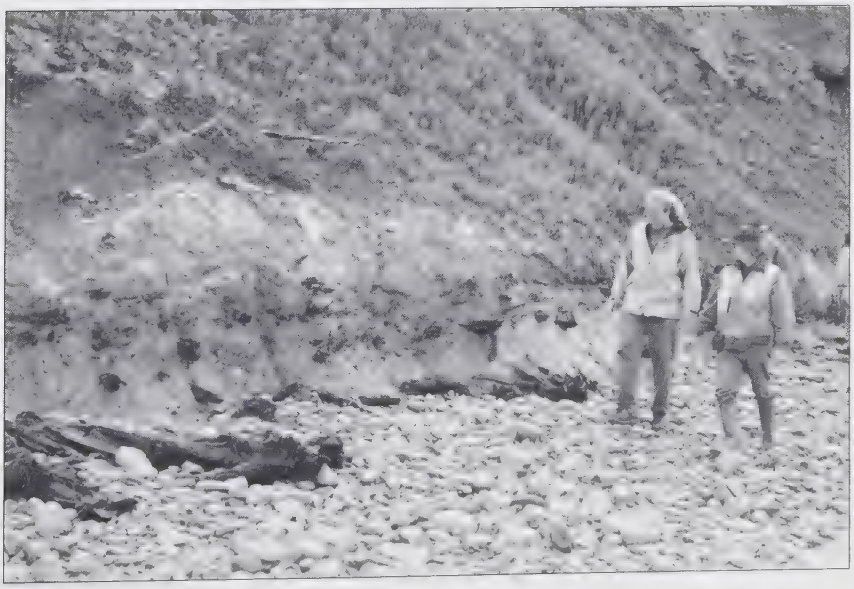

Figure 22. Photograph of bay terrace deposits exposed in sea cliffs south of the village of Cape Meares.

Stop 5. Short Sands, Cove Beach, Arch Cape, Arcadia, Indian Beach

Location (Figure 23): Low terrace sea cliffs along Highway 101, between the Cape Falcon (south) and Tillamook Head (north) headlands.

Features: Evidence of episodically buried peaty horizons in late Pleistocene terrace deposits from Cape Falcon to Tillamook Head.

Site description: Unlike the present coastline, the late Pleistocene coast of northern Oregon had extensive barrier lagoons. These lagoons have left records of episodically buried peaty horizons at many sites (Mulder, 1992) that are not associated with fault-controlled river valleys or faults mapped offshore (Goldfinger and others, 1992). For example, episodically buried peaty horizons in late Pleistocene barrier lagoon deposits are found at many sites between Cape Falcon and Tillamook Head. Although outcrop exposure is not continuous, there is no evidence to suggest that the buried peat horizons are restricted to local structures (faults or fold axes). Furthermore, long-term vertical deformation of the lowest late Pleistocene terrace surface (assumed 80 ka in age) in this area is negligible, e.g., about 10 m (33 ft) elevation change over the distance of 10 km (6 mi) (Mulder, 1992). The late Pleistocene subsidence events recorded here, as in other sites of the northernmost Oregon coast, appear to be located in the zone of elastic deformation, landward of the locked zone.

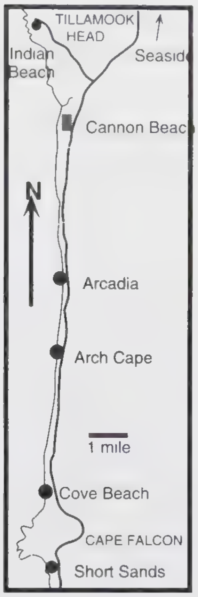

Figure 23. Locations of Stop 5.

Stop 6. Cannon Beach

Location (Figure 24): Ecola wetlands adjacent to Ecola Creek near downtown Cannon Beach. Park near the public rest rooms adjacent to the city park and walk out onto the marsh between the roadways and the waste water treatment ponds.

Features: Examine cores and shallow pits (1 m [3 ft] depth) in wetlands for evidence of the last two prehistoric events of tsunami overtopping of the Cannon Beach barrier spit.

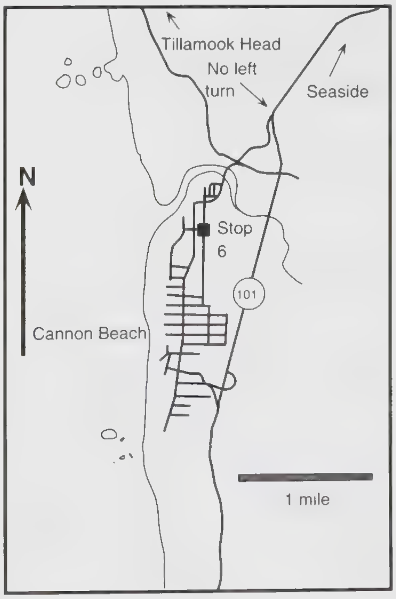

Figure 24. Location of Stop 6.

Site description: The Ecola Creek wetland area behind downtown Cannon Beach (Figure 25) is the first site to yield unequivocal geologic evidence of Cascadia tsunami runup heights at the ocean shoreline (Gallaway and others, 1992). As many as eight buried peats and/or tsunami deposits are recorded in about 3,000 radiocarbon years of deposition in the Ecola Creek wetlands (Figure 26). The uppermost buried peat (younger than 380±60 RCYBP) is associated with a tsunami, whereas the second youngest tsunami (younger than about 1,000 years in age) is located within a peat, i.e., no subsidence. We interpret these tsunami deposits to represent Events 1 and 2 of the five CSZ subsidence events mentioned above. Tsunami-deposit isopach maps indicate that these paleotsunamis entered the wetlands both via the Ecola Creek mouth and by overtopping the southern end of the Cannon Beach spit (Figure 27). Backshore-foredune transitions in the Cannon Beach spit and in many other spits of the Cascadia margin exceed + 5 m (16 ft) MSL (Petit, 1991), yielding CSZ tsunami runup heights of at least 6 m (20 ft) above MSL at Cannon Beach (Figure 28).

Figure 25. Photograph of Friends of the Pleistocene field trip participants in the Ecola Creek wetlands, facing towards the source of the prehistoric tsunami sands (downtown Cannon Beach area) that blanketed the wetlands.

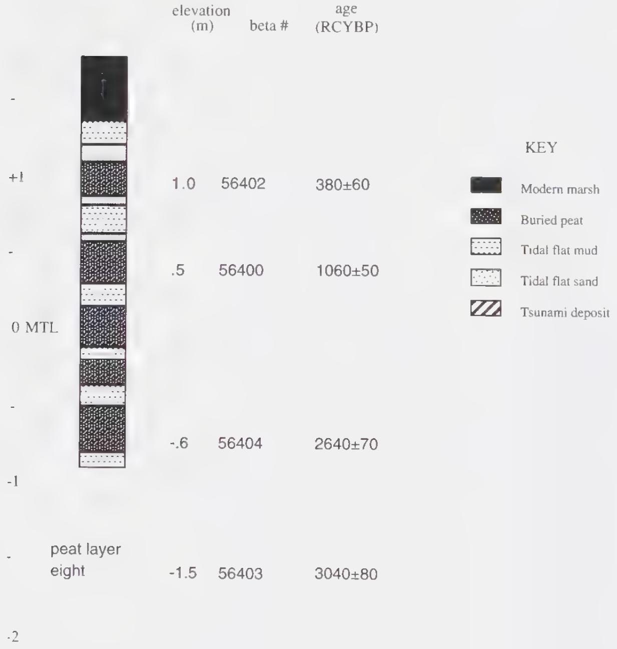

Figure 26. Core log of buried peats from core site northeast of Ecola Creek bend. This log shows thin tsunami sands at the top of uppermost buried peat (38±060 RCYBP) and on the top and bottom of a debris-flow deposit (less than 1,200±60 RCYBP, assumed less than 1,000 RCYBP by correlation to other cores [Gallaway and others, 1992]). A total of eight buried peats are found at this core site (oldest is 3,040±80 RCYBP). The top five peats/tsunami layers (shown in this figure) might be correlative with the last five regional dislocation events (Figure 9). Beta number is radiocarbon laboratory sample number.

The prehistoric CSZ tsunami Event 2 is of particular interest for two reasons. This Cascadia tsunami appears to have propagated well beyond the area of corresponding coastal subsidence in central Oregon (Darienzo, 1991). In addition, it bounds a debris-flow deposit in the northwest corner of the Ecola Creek wetlands (Gallaway and others, 1992). To our knowledge, this is the first debris flow to be tied directly to a megathrust dislocation event in the Cascadia margin. Two and possibly three sand layers from the Event 2 tsunami are associated with the deposition of the debris flow on the wetland surface adjacent to a ravine (Figure 25). The separation of the tsunami layers by the debris-flow sediments confirms multiple wave trains of the Event 2 tsunami. Multiple trains of tsunami waves (two to three) for the Event 2 tsunami are also implied by alternating sand and organic detritus layers at other Ecola Creek wetland sites.

Unlike the prehistoric Cascadia tsunamis, the significant flooding from the historic 1964 Alaskan tsunami was limited to the Ecola Creek mouth area. The preexisting Ecola Creek bridge at the north end of Cannon Beach was removed from its footings and carried about 150 m (500 ft) up the Ecola Creek channel by that tsunami (Terry Swagert, Cannon Beach resident, personal communication, 1992). No historic tsunami deposits have been identified in the Ecola

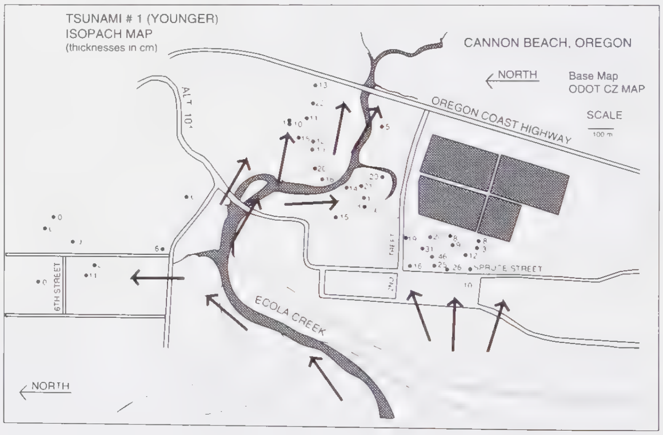

Figure 27. Isopach map of youngest prehistoric tsunami (300 Cal. Year BP) deposit thickness at Cannon Beach. Maximum deposit thickness at south end of Cannon Beach spit indicates spit overtopping as well as surge propagation up the Ecola Creek channel. Arrows show direction of tsunami movement.

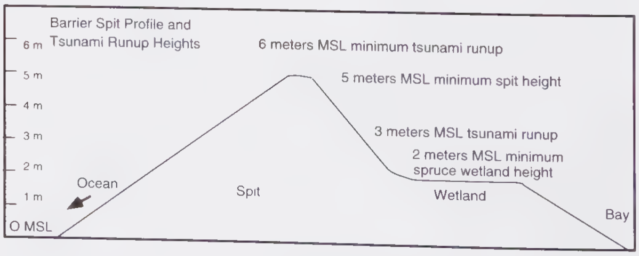
Barrier Spit Profile and Tsunami Runup Heights
6 m
5 m
4 m
3 m
2 m
1 m
O MSL
6 meters MSL minimum tsunami runup
5 meters MSL minimum spit height
3 meters MSL tsunami runup
2 meters MSL minimum spruce wetland height
Ocean
Spit
Wetland
Bay

Figure 28. Generalized diagram of tsunami overtopping spit of assumed elevation (+5 m MSL). Estimated minimum runup height of CSZ tsunamis at Cannon Beach ocean shoreline is +6 m MSL (Gallaway and others, 1992).

Creek wetlands except for small remnants of the destroyed bridge that were found immediately adjacent to the Ecola Creek channel. The wetland areas of tsunami inundation and deposition for the last two prehistoric Cascadia tsunamis are at least ten times larger than that for the 1964 Alaskan tsunami in the Ecola Creek wetlands.

Stop 7. Seaside overview at Tillamook Head

Location (Figure 29): Take the beach access route off Highway 101 at the south end of Seaside to drive west to the Tillamook Head overlook. Park along the roadway or hike out to the sea cliff above the Seaside cove for a broad overview of the south end of the Clatsop spit area.

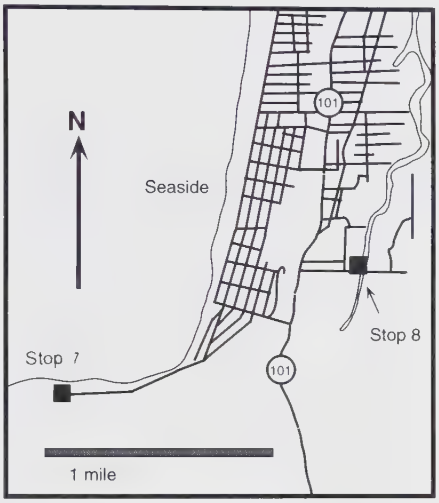

Figure 29. Locations of Stops 7 and 8.

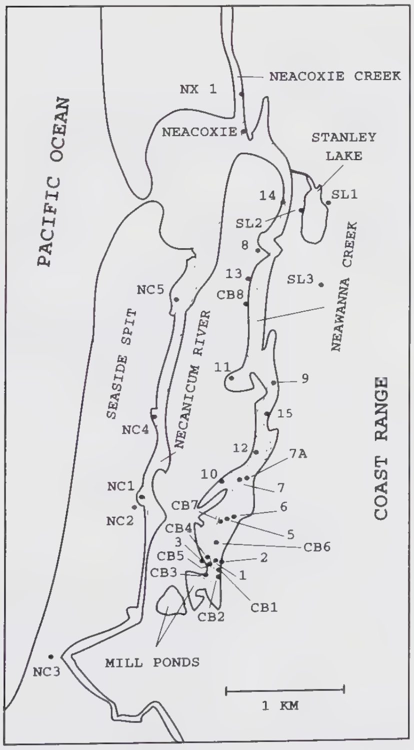

Figure 30. General map of Seaside area, showing location of cores taken and cutbanks (CB) examined.

Features: Beach cobble ridges, Necanicum and Neawanna River morphology, and probable historic tsunami deposits in Necanicum River.

Site description: The Seaside area is developed on Clatsop Spit, which extends south to Tillamook Head and north to the Columbia River. Gravel beach ridges and dunes prograded westward, due to diminished rates of eustatic sea-level rise during late Holocene time (Rankin, 1983). The source of the gravels, which range up to cobble size, is the Tillamook Head basalt. Gravel beach ridges are separated by small, linear valleys that contain the Necanicum River, Neawanna Creek, and Stanley Lake wetlands (Figure 30).

The marshes of the Necanicum River valley contain two distinct sand layers sandwiched between rooted muds within 1 m (3 ft) depth (Figure 31) (Darienzo and others, 1993). The sands can be traced over 2 km (1.2 mi) from core site NC2 to NC5 (Figure 30). Radiocarbon dates and historic artifacts indicate that the anomalous sand layers are historic. Neither layer is associated with abruptly buried peats, further distinguishing them from prehistoric Cascadia tsunamis. However, historic tsunamis are known to have surged into Necanicum Bay. Walls of water 3 m (10 ft) high and 1.2 m (4 ft) high, respectively, are reported to have traveled up the Necanicum River as a result of tsunamis produced by the 1964 and 1946 Alaskan and Aleutian earthquakes. Sand from the 1964 tsunami was deposited on the Highway 101 bridge, where it crosses the Neawanna Creek (Neal Maine, Seaside Public Schools, personal communication, 1992). There is no evidence that the historic Alaskan tsunamis left any sandy deposits in the Neawanna Creek wetlands behind Seaside.

The young Necanicum River valley has no prehistoric marsh deposits; thus we have no record of paleotsunami inundation along Seaside's ocean frontage areas. However, geologic evidence of prehistoric tsunami inundation landward of Seaside is well preserved in the Neawanna and Stanley Lake wetlands (see Stop 8 below).

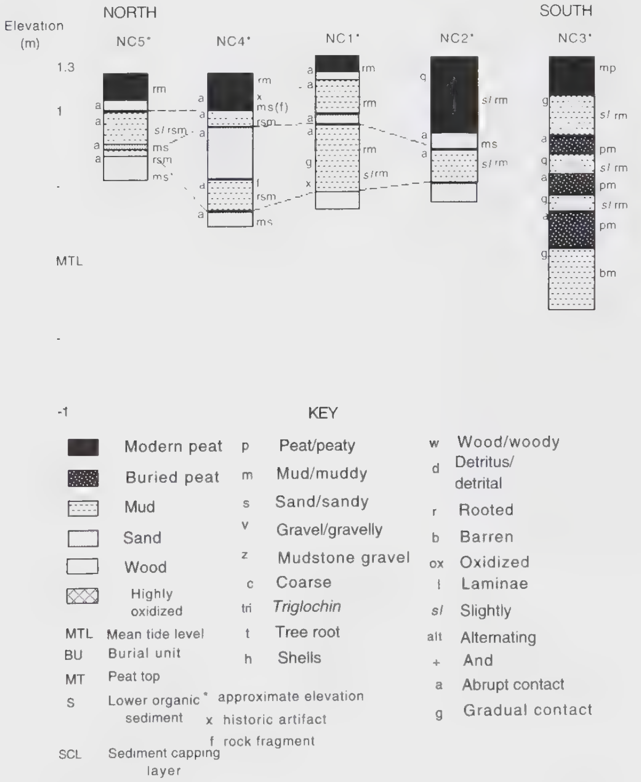

Figure 31. Stratigraphy of historic sand layers (probable 1946 and 1964 Alaskan tsunami deposits) in Necanicum River.

Stop 8. Neawanna cutbank

Location (Figure 29): At the south end of Seaside, turn off Highway 101 to travel east on S Ave. about ⅓ mi to the bridge crossing over Neawanna Creek. Park and walk north, out onto the marsh, or along the cutbank on the east side of the Neawanna tidal creek. **Requires low tide.**

Features: Coseismically buried peats, tsunami-deposited sand, and debris-flow deposits.

Site description: The upper reaches of the Neawanna tidal channel contain evidence for six coseismic burial events in the last 2,200 RCYBP. The coseismic subsidence events are denoted by abruptly buried peats, tsunami sands, and some debris-flow deposits (Darienzo, 1991) (Figure 32). Tree roots protruding from peaty horizons in the cutbanks indicate that some of the paleowetlands here were forested prior to coseismic subsidence and burial.

The debris-flow deposits overlying the buried peats are characterized by chaotic structure and poorly sorted clay and gravel. The gravel contains rounded mudstone fragments that are easily crushed between the fingers. One debris-flow deposit (20–30 cm [8–12 in.] thick) can be traced in the cutbank over a distance of 80 m (260 ft) between core sites CB5 and CB6, where it gives way to sand at CB6 (Figure 30). Debris-flow deposits are not found downstream of core site 7, confirming an upland/upstream source. Additional work is needed to constrain the relative timing of the debris-flow deposits with respect to tsunami inundation. However, beach sand is mixed in with some of the muddy gravel deposits, suggesting the potential for codeposition from tsunami and debris-flow sources.

The sandy tsunami deposits in the Neawanna core sites pinch out (from 26 to 0 cm [100 in.] thickness) with distance down the tidal

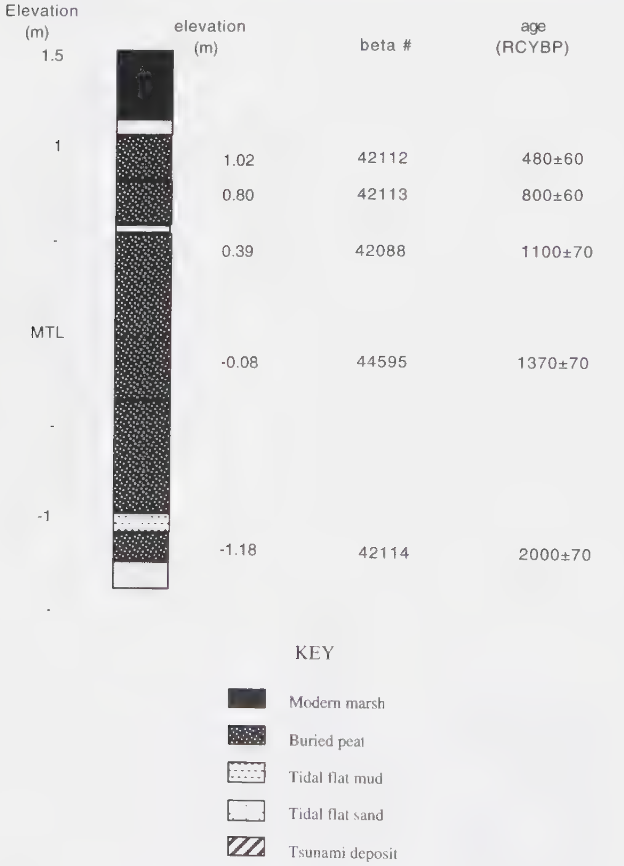

Figure 32. Stratigraphy and radiocarbon ages of buried peats from core site 2 along the upper reaches of the Neawanna. Beta number is radiocarbon laboratory sample number.

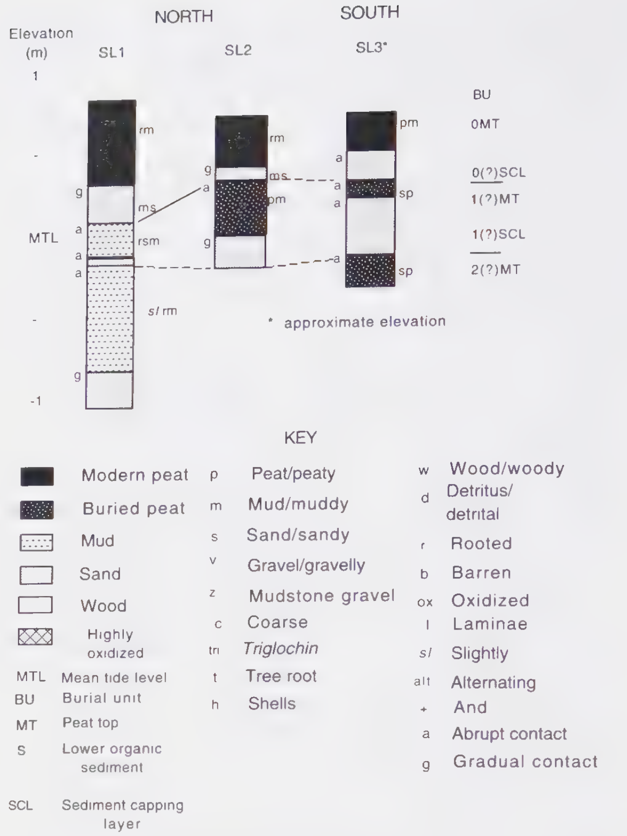

Figure 33. Stratigraphy of representative cores in the Stanley Lake area.

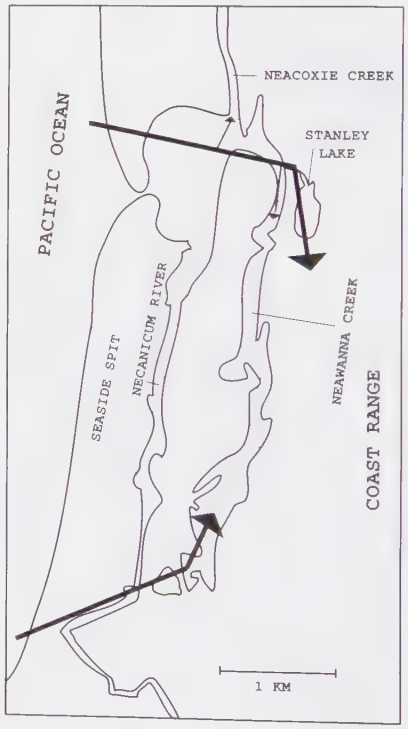

Figure 34. Arrows show probable directions of movement of the tsunami surges for the last two Cascadia earthquakes. The thicker arrows depict the main surge corridors and the thinner arrows other possible corridors.

channel (to the north). A northward propagation of the tsunami surge here is also supported by the sand mineralogy, indicating a beach sand supply from the west, as opposed to a river sand supply from upstream or downstream. The beach sands are discriminated from river sands on the basis of heavy mineralogy and relative grain rounding (Darienzo and others, 1993). The paleotsunamis that deposited beach sands in marshes of the upper Neawanna tidal channel are interpreted to have surged through or over the spit at the south end of Seaside.

However, even thicker paleotsunami deposits are found in the Stanley Lake area, northeast of Seaside (Figure 33). The sand layers range from 4 to 68 cm (1.5–27 in.) in thickness and contain from 75 to 100 percent beach sand components. The uppermost sand layer(s) in Stanley Lake was (were) deposited within the last 800 years RCYBP, suggesting deposition from one or both of the last two Cascadia tsunamis. The lack of an intervening peat might reflect scouring by the last paleotsunami (CSZ Event 1), but this hypothesis will require AMS radiocarbon dating for confirmation. The mineralogy and thickness of the tsunami sands here indicate that the tsunami surges breached the ridge between the Necanicum bay mouth and the Stanley Lake valley before dissipating with distance south along the Stanley Lake valley. At the south end of the Stanley Lake valley, the CSZ Event 1 and Event 2 tsunamis are separated by a peaty horizon. The patterns of Cascadia tsunami propagation in the Seaside area are complex (Figure 34), with surges crossing gravel ridges at low points and dissipating in intervening lowland valleys between the gravel ridges.

Stop 9. Youngs Bay, Columbia River

Location (Figure 35): Drive north toward Warrenton, but head east on Oregon Coast Highway 101 alternate (old Hwy 101) toward Astoria. Park at the west end of the bridge and walk north out on a dike road to view tidal creek cutbanks in the northeast corner of the small marsh.

Features: Marsh cutbank and/or shallow cores show evidence of two paleotsunami deposits about 10 km (6 mi) upriver of the Columbia River mouth.

Site description: This marsh site is located at the west side of Youngs Bay, between Warrenton and Astoria, in the lower Columbia River estuary. There has been much speculation about Cascadia tsunami runup in the Columbia River. The 1964 Alaskan tsunami is reported to have nearly topped dikes along the Warrenton shoreline that were 3 m (10 ft) high. The two paleotsunami deposits recorded at this site clearly indicate sufficient tsunami runup to overtop high marsh settings some 15 km (9 mi) from the mouth. However, the Columbia River tidal inlet has been substantially altered in historic time. Numerical tsunami modeling will likely be required to evaluate the importance of historic inlet changes in controlling potential runups of future Cascadia tsunamis.

A general core log for the shallow marsh stratigraphy at this site is shown in Figure 36. The upper tsunami layer is associated with marsh burial and is presumed to be CSZ Event 1, at about 300 years ago. The lower tsunami layer is not associated with coastal subsidence and is tentatively correlated with CSZ Event 2. These deposits have yet to be radiocarbon dated. It is interesting to note that at this site the tsunami layer associated with local subsidence is thinner than the tsunami layer not associated with local coastal subsidence. This site possibly extends the propagation distance of the CSZ tsunami Event 2 at least 100 km (62 mi) beyond the area of observed coastal subsidence in central Oregon (Peterson and Darienzo, 1992).

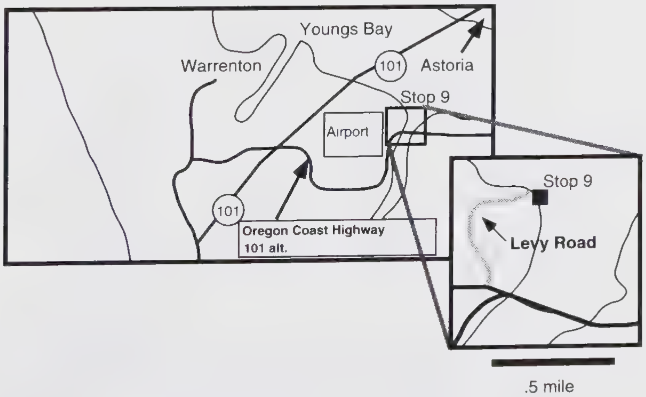

Figure 35. Location of Stop 9.

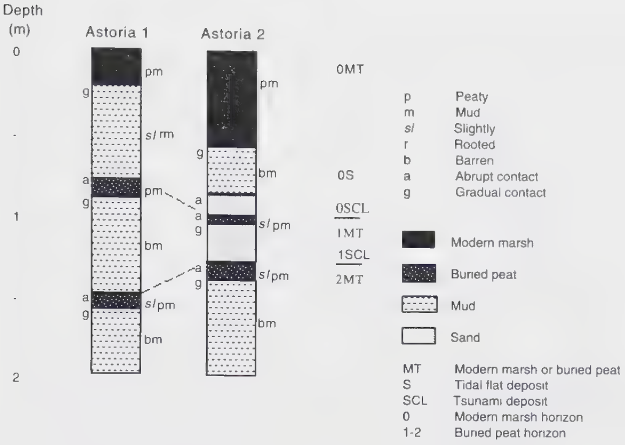

Figure 36. Stratigraphy of last two Cascadia tsunamis (Events 1 and 2) in Youngs Bay-Warrenton area of lower Columbia River.

Stop 10. Nestucca Bay marsh

Location (Figure 37): Highway 101 bridge area over Nestucca River as it enters Nestucca River valley between Woods and Pacific City. The prehistoric wetlands are now pasture lands. River banks have been diked, so marsh stratigraphic examination requires coring or shallow pits in the pastures. **Permission for access to the pasture lands is required from the owners.**

Features: Coseismically buried peats and tsunami-deposited sands. This site has the largest number of buried peats (12) reported to date for the central Cascadia margin.

Site description: Nestucca Bay is fed by the Nestucca and Little Nestucca Rivers and is separated from the Pacific Ocean by a long sand spit (Figures 1 and 38). There are very few natural marshes in the area due to the extensive diking of wetlands for grazing of dairy cattle. Nevertheless, coseismically buried peats were identified beneath pasture soils along both rivers (Figure 38) (Darienzo, 1991). The strongest evidence for coseismic peat burial with tsunami deposition is at the Nestucca Duck sites, which record CSZ Event 1, about 300 years in age (Figure 38). However, thin tsunami layers (1 cm [0.4 in.] thick) that are associated with several buried peat horizons have been traced upriver to the Hurliman 4 site and to sites along the lower reaches of the little Nestucca channel (Figure 38).

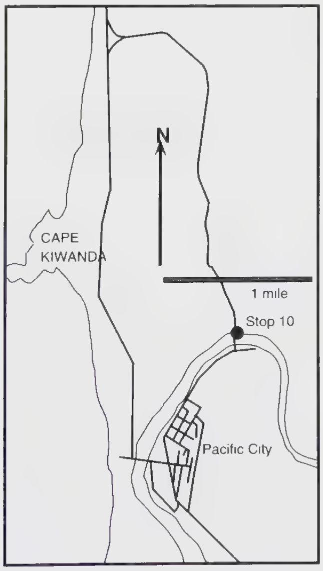

Figure 37. Location of Stop 10.

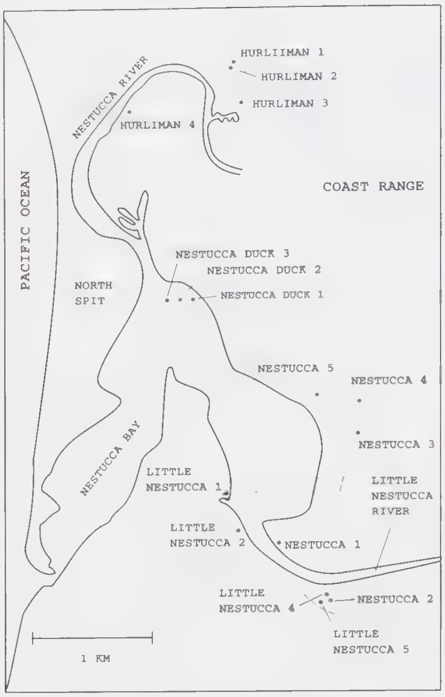

Figure 38. General map of Nestucca Bay with core site locations. The areas outlined with the wide dashed lines are pasture land and short dashed lines tidal marshes.

The deepest paleoseismological core taken in the Pacific Northwest was from the Hurliman 2 core site (Figure 39). Some 12 burial events were identified in 13 m (43 ft) of core depth at that site. The deepest buried peat yielded a radiocarbon age of approximately 5,700 RCYBP. The average recurrence interval of the upper six burial events is similar to that calculated for the lower six burial events, i.e., about 400–500 years. The average long-term recurrence interval for this central Cascadia site (12 buried peats in 5,700 years) is somewhat shorter than that estimated from offshore turbidites, i.e., 500–600 years, based on 13 turbidites in the last 6,700 years) (Adams, 1990).

Stop 11. Neskowin

Location (Figure 40): Walk the beach south of Neskowin in winter for evidence of standing forest stumps in the surf zone. **Requires low tide.**

Features: Late Holocene forest developed on wave-cut platform that is now in the surf zone.

Site description: A forest of tree stumps (more than 100 in number) is occasionally exposed in the surf zone immediately south of the town of Neskowin (Figure 41). This forest likely corresponds to one of several buried wetland horizons in the Neskowin River valley behind the beach. A radiocarbon age of one standing stump in the forest is approximately 2,000 RCYBP (C.D. Peterson and B. Paul, unpublished data, 1990). This forest is located on a Holocene wave-cut platform that was initially cut below sea level. It then emerged above sea level to grow the forest, then submerged below sea level, where it now stands in the surf zone. Abrupt subsidence and burial by beach sands are thought to have preserved the forest in its present sea-level position. The recognition of similar surf zone forests on the Oregon coast (1983–1985) helped focus the attention of some of these authors on late Holocene sea-level changes in the central Cascadia margin.

The Oregon coast consists of segments of sandy beaches, called littoral cells, that are separated by headlands or other barriers. Movement of sand up and down the coast is generally confined to each cell, with the headlands or other barriers inhibiting transport of sand from

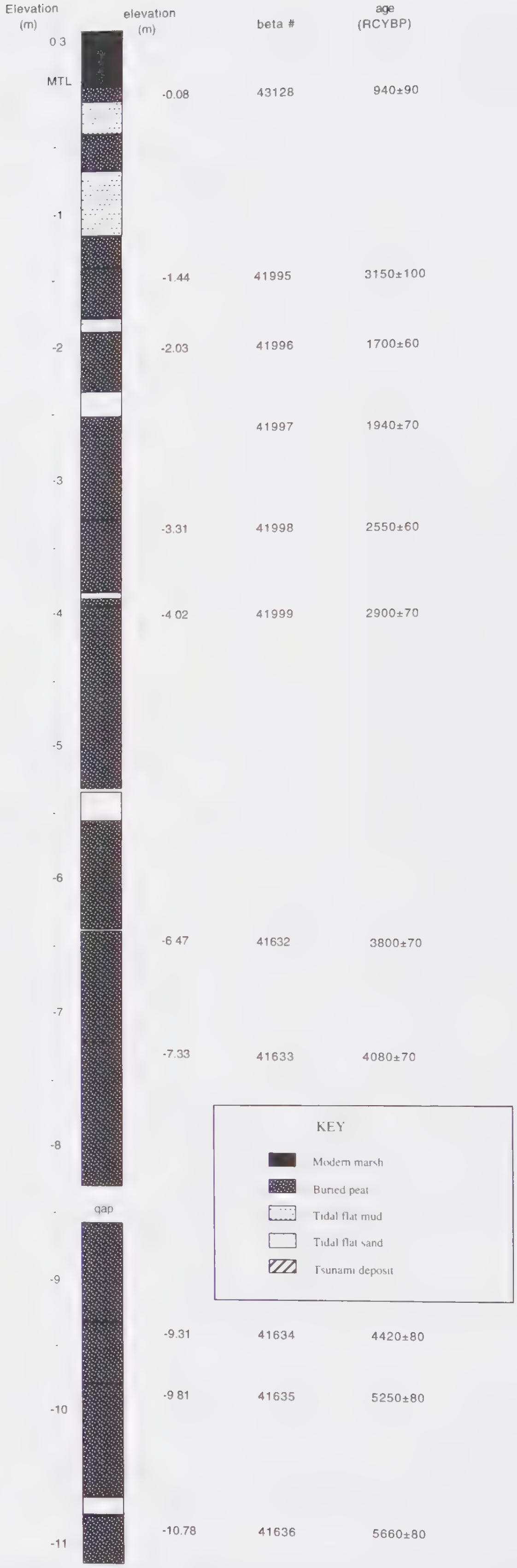

Figure 39. Radiocarbon ages of buried peats from Hurliman 2 and Little Nestucca 5. Beta number is radiocarbon laboratory sample number.

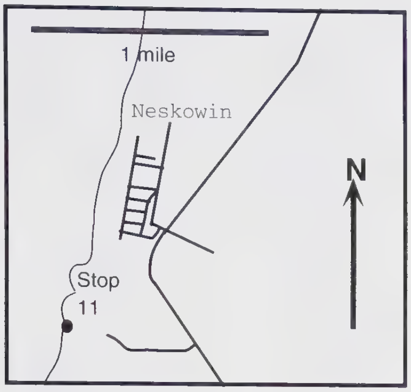

Figure 40. Location of Stop 11.

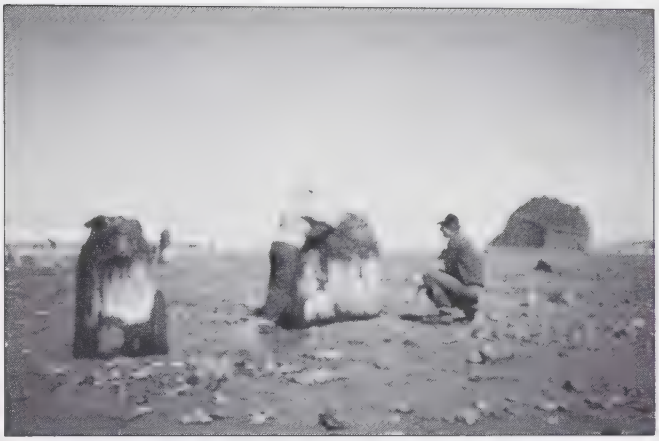

Figure 41. Photograph of large stumps developed on late Holocene wave-cut platform now in the surf zone. Age of one tree is about 2,000 RCYBP.

one cell to another. Progradational beaches north of Neskowin contrast sharply with widespread shoreline retreat in the Lincoln City cell to the south. The two cells differ in sand supply, even though the adjacent cells are similar in size, river drainage-basin area, and predicted rate of uplift (Goldfinger and others, 1992). We hypothesize that sand is excavated from bluffs in the Lincoln City cell and bypassed around Cascade Head to supply the Neskowin-Pacific City cell. Such a process could be accelerated during periods of beach and sea cliff erosion following coseismic subsidence.

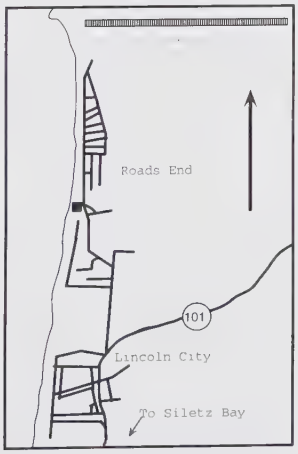

Figure 42. Location of Stop 12.

Stop 12. Roads End Beach Wayside

Location (Figure 42): At the north end of Lincoln City find Roads End intersection with Highway 101 (McDonalds Restaurant on opposite side of intersection). Take road north to the Roads End Beach Wayside parking lot. Walk down the path to the beach and head south 300 ft to view the late Pleistocene sea cliffs.

Features: Coseismic liquefaction features (convolute bedding) in late Pleistocene marine-terrace deposits.

Site description: The late Pleistocene terraces (assumed 80 ka in age) contain highly convoluted heavy-mineral layers that were originally deposited in planar foreshore beds (Figure 43). These convoluted beds are associated with clastic dikes, sills, and vent-collapse structures in many of the Oregon marine terrace deposits (Peterson and Madin, 1992). The tops of the convoluted beds at this site are eroded, proving the liquefaction to have occurred during the period of marine terrace deposition and not during the subsequent 80,000 years (Figure 44). Higher up in the section, some transitional backshore to eolian dune sands show a second liquefaction event. Some sites in the Lincoln City terraces show as many as three distinct liquefaction events that occurred during the period of deposition, near the end of that marine transgression.

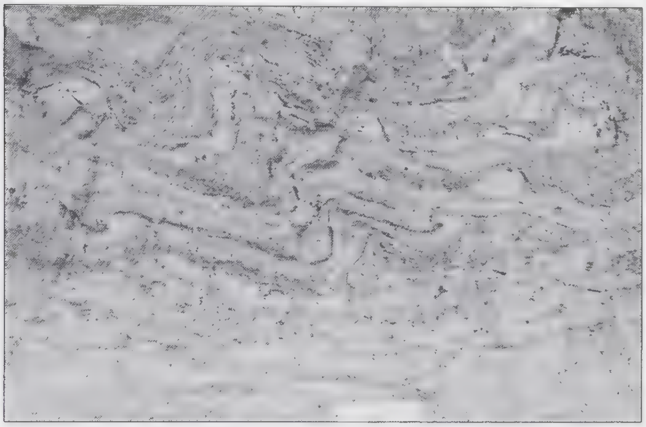

Figure 43. Photograph of highly convoluted beds in marine terrace deposits.

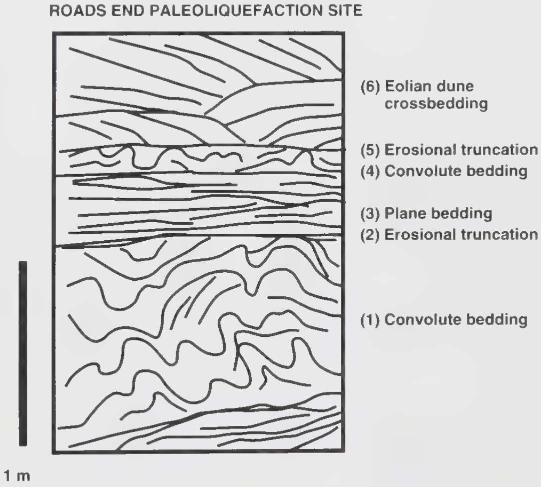

Figure 44. Convoluted foreshore deposits (liquefaction) are truncated by overlying planar beds. A second liquefaction event is represented by smaller scale convolute beds in overlying dune deposits. Liquefaction in dune deposits generally corresponds to permeability caps under interdune pond sediments. High pore pressure allowed localized liquefaction above the water table.

Stop 13. Salishan Spit, Siletz Bay

Location (Figure 45): Stop at the office of Salishan Lease Holders, Inc., on the west side of Highway 101, opposite Salishan Lodge. With permission, drive out to the Siletz Bay spit. Park at the north end of the Golf course and walk east on a dirt access road to about half the length of the fairway. Leave the road and walk north 300 ft through trees and/or brush to wetland areas.

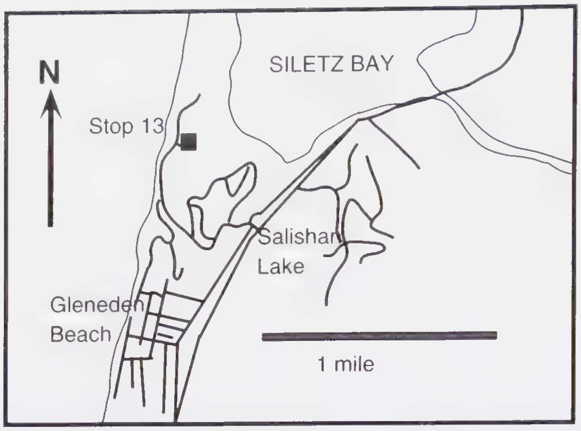

Figure 45. Location of Stop 13.

Features: Coseismically buried peats and tsunami-deposited sands.

Site description: Siletz Bay is separated from the Pacific Ocean by a spit that now contains an artificially stabilized foredune and numerous residences (Figures 1 and 46). Six coseismically buried peats with overlying tsunami deposits up to 25 cm (10 in.) thick are identified in marsh deposits along the spit and across the bay in the Millport Slough area (Darienzo, 1991) (Figures 46 and 47). The Salishan House site at the southern end of the spit contains particularly well-developed buried peats and overlying tsunami sands.

This is an example of one of our tsunami sensitive sites. The tsunami sands on the spit are derived directly from the beach (spit overtopping) except for the fifth buried peat, which shows a significant river sand component. Since the bay deposits adjacent to the spit are predominantly of river sand mineralogy (Peterson and others, 1984), a tsunami that propagated up the bay would deposit a mixed (beach/river) sand mineralogy. The overtopping of the spit by three of the last four paleotsunamis substantiates estimates of tsunami runup (+ 6 m [20 ft] MSL) predicted from the Cannon Beach sites discussed above. Additional work is needed here to establish the age of the topmost tsunami layer, which is contaminated by young roots descending from the modern wetlands.

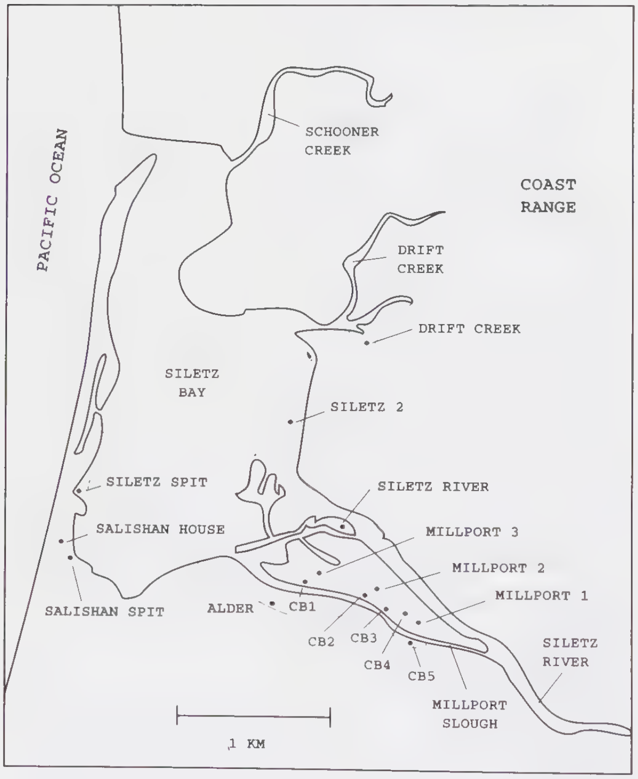

Figure 46. General map of Siletz Bay showing core site locations. Dashed lines show cored marsh areas.

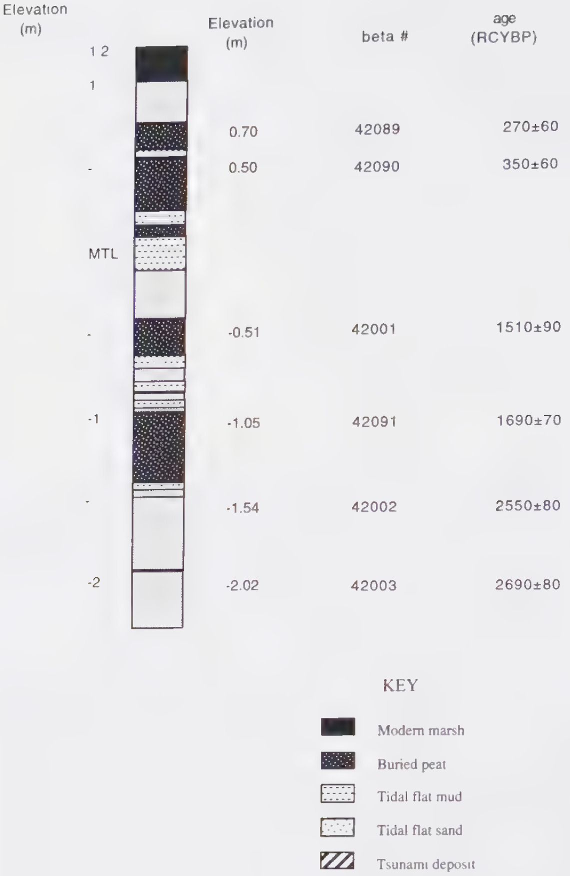

Figure 47. Radiocarbon ages of buried peats from Salishan House. Beta number is radiocarbon laboratory sample number.

Stop 14. Millport Slough, Siltez Bay

Location (Figure 48): Turn east off Highway 101 at Alder Road, immediately north of Salishan Lodge. Take the road to a small bridge over a tidal channel (Millport Slough). Explore cutbanks southeast of the Millport Slough bridge to find one to three buried wetland horizons. **Requires low tide.**

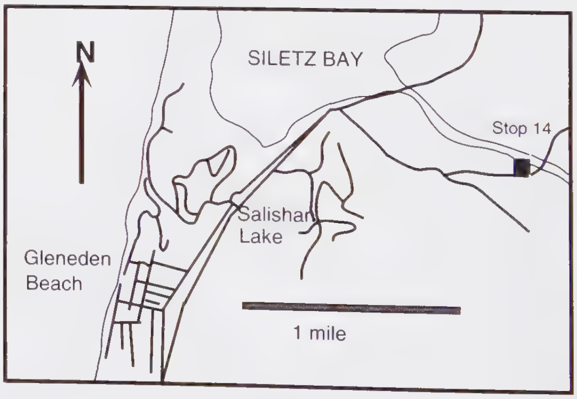

Figure 48. Location of Stop 14.

Features: Several buried wetlands in tidal creek cutbanks; additional buried peats and tsunami deposits in deeper cores.

Site description: This distal marsh site (Figure 46) is located well upriver of the bay mouth and ocean shoreline. It shows evidence of multiple uplift and subsidence cycles (Figure 49). Sufficient sediment supply during aseismic uplift cycles permitted the development of forested wetlands prior to subsequent subsidence events. Tsunami layers directly overlying buried peats are thin and discontinuous this far up the bay, but they do occur locally above the fourth, fifth, and seventh buried peats (Figure 49).

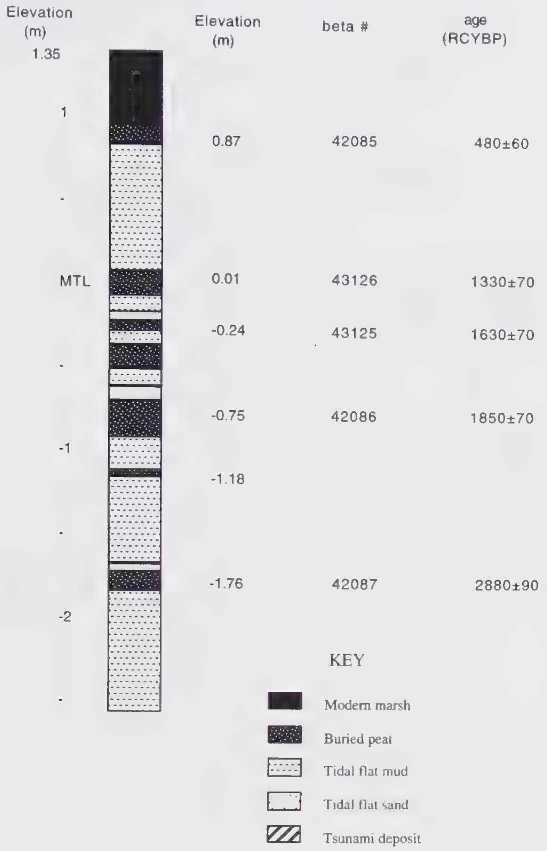

Figure 49. Radiocarbon ages of buried peats from Millport Slough. Beta number is radiocarbon laboratory sample number.

Stops 15 and 16. Gleneden and Lincoln Beaches

Location (Figure 50): Here we describe two separate late Pleistocene liquefaction sites. The Gleneden site is easily accessed from the Gleneden Beach Wayside, about 1 mi west of Highway 101. Walk down the beach access trail and continue north (30–650 ft) to view the sea cliffs. The Lincoln Beach site can be accessed by a long beach walk, or with permission from the Sea and Sand Trailer Park owners. From the Trailer Park, just north of Lincoln Beach, walk north (160 ft) to view the sea cliff deposits.

Features: Coseismic liquefaction features (flames, sills, and dikes) in late Pleistocene marine terrace deposits.

Site description: At the Gleneden Beach Wayside site are well-exposed examples of injection flames and lateral sills in late Pleistocene beach and dune deposits (assumed age 80 ka). The largest flame structure (> 1 m [3 ft] in height) at this site is located under a slight overhang at a distance of about 100–150 m (300–500 ft) north from the beach access path. The smaller clastic sills throughout the outcrop (Figure 51) are representative of liquefaction evidence at many late Pleistocene coastal terrace sites in Oregon and Washington (Peterson and Madin, 1992). The sills are identified by injection terminations of primary bedding at both upper and lower sill contacts (Figure 52).

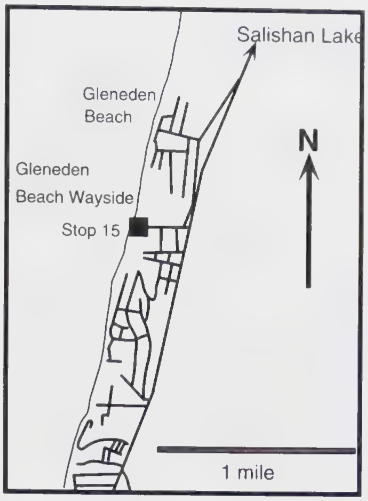

Figure 50. Location of Stop 15; Stop 16, not shown, is located on the beach 2 mi south of Stop 15.

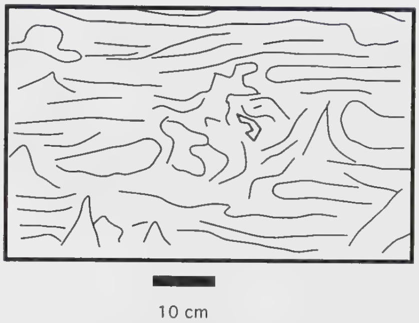

Figure 51. Line drawing of clastic sills and small flame structures in coarse backshore sands from a late Pleistocene marine terrace deposit at the Gleneden Beach site.

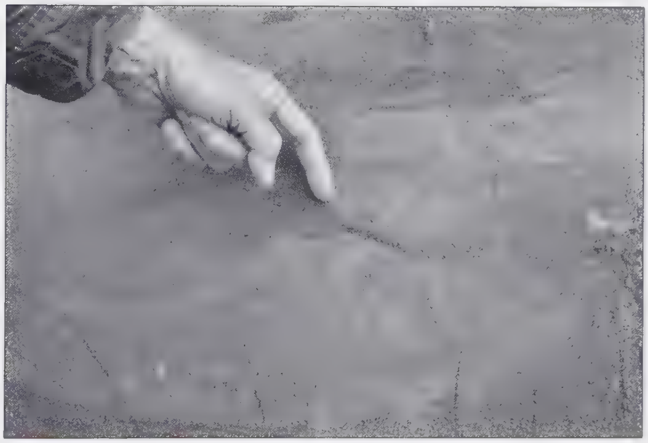

Figure 52. Photograph of clastic sills in backshore beach deposits of late Pleistocene marine terrace.

The liquefaction features at the Sea and Sand Trailer Park site include large-scale vertical and horizontal injections that have dismembered horizontal peats in muddy deposits (10–15 m [30–50 ft] outcrop length). These deposits are thought to represent a back-berm lagoonal setting, as evidenced by the basal channel contacts in beach/barrier deposits. The sand injections actually represent two different episodes of coseismic liquefaction. The initial injection event(s) occurred during the period of deposition

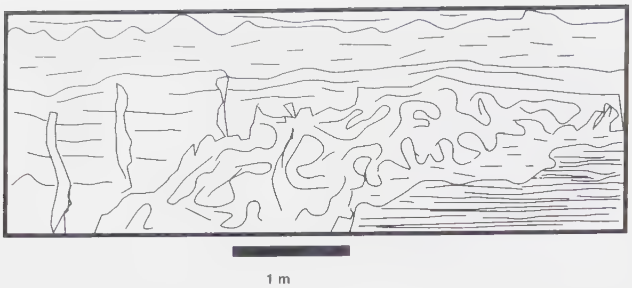

Figure 53. Line drawing of late Pleistocene lagoonal deposits showing two episodes of coseismic liquefaction at Lincoln Beach Trailer Park. Thin peaty layers in the section are dismembered by vertical and horizontal sand injections. These severely disturbed beds underlie an undeformed silty layer (< 0.5–1 m [2–3 ft] thick) that caps the section. Thin vertical cracks are filled with unweathered sand that is much younger (no iron staining) than the weathered lagoonal deposits.

of the section (about 80 ka) followed by subsequent weathering of the deposits. A second set of thin vertical cracks (50-cm [20-in.] spacing) cut the weathered deposits, and these cracks are filled with unweathered sands (possibly Holocene? in age), suggesting a more recent event of injection(s) (Figure 53).

ACKNOWLEDGMENTS

Support for the research that has been conducted at many of these field trip stops has been provided by Oregon Sea Grant College Program, National Earthquake Hazards Reduction Program, National Science Foundation, Oregon Department of Geology and Mineral Industries, Federal Emergency Management Agency, and the Clatsop County Sheriff's Office.

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DOGAMI releases publication updates

Three new releases of the Oregon Department of Geology and Mineral Industries (DOGAMI) represent updates of earlier publications: the annual report and map of the Mist Gas Field, the database of mineral localities, and the directory of mineral producers in the state.

Mist Gas Field Report
Open-File Report O–93–1

The Mist Gas Field Report is now available with all activity and changes for the year 1992. The report includes (1) the Mist Gas Field Map, showing location, status, and depth of all wells, and (2) the listing of production figures from the initial production in 1979 through the end of 1992, showing well names, revenue generated, pressures, annual and cumulative production, and other data. The new Mist Gas Field Report is DOGAMI Open-File Report O–93–1 and sells for $8.

Mineral Information Layer for Oregon (MILOC)
Open-File Report O–93–8

MILOC is a database in dBase III+ format that can be imported into computerized geographic information systems or used with a personal computer as a stand-alone, county-by-county database. For use as a mineral-data layer, each site is located by both latitude/longitude and Universal Transverse Mercator (UTM) coordinates.

The database provides information on nearly 8,000 mineral occurrences, prospects, and mines in Oregon. Records on individual sites include a great variety of data on location, commodity, geology, descriptions of mine workings, and many other subjects. The updated version has been made more user-friendly and, in response to input from users, contains some changes in the structure of the records.

The database comes as a set of two 1.2-megabyte (5¼-inch, high-density) diskettes in MS-DOS format and sells for $25. Owners of the first edition may exchange their original diskettes for the new ones at the reduced price of $15.

Directory of Mineral Producers in Oregon
Open-File Report O–93–9

The *Directory of Mineral Producers* was derived from a Departmental computer listing originally designed for internal use. Its updated version includes approximately 1,000 production sites operated by about 550 mineral producers and includes more exploration companies than the earlier version.

The 56-page directory contains two tables: Table 1 is arranged alphabetically by commodity and operator, covering over 30 commodities—from "Abrasives" to "Zeolite"—and listing producers with addresses and township/range designations of their operating sites. Table 2 is arranged alphabetically by county and commodity, showing in abbreviated form which commodities are produced by whom in a given county. The price for the new directory, Open-File Report O–93–9, is $8.

The new reports are now available over the counter, by mail, FAX, or phone from the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; and the DOGAMI field offices in Baker City: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and Grants Pass: 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. ☐

Position Announcements
Oregon Department of Geology and Mineral Industries

Geotechnical Engineer/Seismic Hazard Geologist/Engineering Geologist

The Oregon Department of Geology and Mineral Industries seeking to hire a geologist, engineering geologist, or geotechnical engineer to participate in seismic hazard studies. The minimum qualifications are a master's degree in geology, engineering geology, geotechnical engineering, or geophysics. Duties will include geologic mapping, geologic computer modeling, shallow seismic reflection profiling and other detailed geophysical surveys, fault trenching, paleoliquefaction studies, design, contracting, and execution of drilling and cone penetrometer programs, and other tasks necessary to identify earthquake sources and map the geologic component of earthquake hazard in western Oregon urban areas. In addition to the minimum educational requirements, applicants should have significant experience in two or more of the specific areas listed above. Excellent written and oral communication skills, particularly with nontechnical audiences and media, are essential. Applicants with significant mathematics, engineering, and computer background will be more competitive. This position will commence in late 1993 or early 1994, and the position is guaranteed through July 30, 1995, with the possibility of continuation beyond that date. Salary is commensurate with experience; negotiations will start at $2,606 per month, with an excellent benefit package. This position will be stationed in Portland, Oregon. Field work in the Willamette Valley and along the Oregon coast will be required. Interested applicants should send a resume and cover letter to Ian Madin, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street # 28, Portland, OR 97232. Resumes will be accepted until October 1, 1993. After that date, necessary application materials and an explanation of the hiring process will be provided to applicants.

Minerals Economist

The Oregon Department of Geology and Mineral Industries is seeking to hire a minerals economist to participate in data collection, data analysis, and communication regarding the economics of mineral production in the state with attention to demand for aggregate and other mineral commodities.

Duties will include developing data and models for mineral production in Oregon, participating in select mineral economic issues in parts of Oregon, completing an annual list of Oregon mineral producers, and developing new reports of selected case studies of mineral production in various parts of the state.

Minimum qualifications include proficiency in statistics, excellent communication skills, excellent interpersonal qualities under a variety of conditions, and training in economics. Experience in mineral economic analysis and computer skills are desirable. Applicants with significant qualifications in these categories will be the most competitive.

This position will begin in early 1994 and is guaranteed through June 1995, with the possibility of continuation beyond that date. Salary is commensurate with experience.

The position is stationed in Portland, Oregon. Travel throughout Oregon will be required.

Interested applicants should send a resume and cover letter to Don Hull, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street # 28, Portland, OR 97232. Resumes will be accepted until November 15, 1993. After that date, necessary application materials and an explanation of the hiring process will be provided to applicants.

Reclamationist

The Oregon Department of Geology and Mineral Industries Mined Land Reclamation program will soon have a position opening for a reclamationist.

The reclamationist conducts field inspections of proposed and active mining operations, produces site compliance reports, calculates reclamation bonds, and participates in technical reviews as part of an interdisciplinary team.

Qualifications for a reclamationist typically include at least a bachelor's degree with a major in environmental, biological, or physical science, or in engineering and at least one year of experience in reclamation, environmental coordination, or engineering. Preference is given for experience in mining.

Anyone sending a resume will receive a formal announcement of the job opening at the time the position officially opens. Expected hiring is January 1994. Starting salary range is $2,606–$2,871 per month plus excellent benefits.

If you are interested, please send a resume and cover letter to Department of Geology and Mineral Industries, Attn: Recruiting, 1536 Queen Avenue SE, Albany, OR 97321.

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Historical earthquakes in and around Portland, Oregon

by Jacqueline D.J. Bott and Ivan G. Wong, Woodward-Clyde Federal Services, 500 12th Street, Suite 100, Oakland, California 94607

ABSTRACT

A reevaluation of all known moderate-sized earthquakes in the Portland area has revealed that at least 17 events of Richter magnitude (M_L) 4 and larger have occurred in historic time; six events have been M_L 5 and greater. These observations indicate that the Portland region is the most seismically active area in Oregon. Based on the historical record, recurrence estimates suggest that a M_L 5.5 and larger earthquake will occur about every 100 to 150 years and a M_L 6 and larger earthquake every 300 to 350 years. A crustal earthquake of M_L 6 or greater could generate a greater level of ground shaking in the Portland metropolitan area than could a moment magnitude (M_W) 8+ event on the Cascadia subduction zone and thus needs to be considered in seismic hazard evaluations of the region.

INTRODUCTION

Fewpeople realize that the region centered on the city of Portland is possibly the most seismically active area within the state of Oregon. The Richter magnitude (M_L; see Table 1) 5.6 Scotts Mills earthquake of March 25, 1993 (Figure 1), which shook most of western Oregon and southwestern Washington, is the largest event known to have occurred in northwestern Oregon and attests to the earthquake potential of the region. The absence of larger events in the historical record, however, has led to the general belief that larger events cannot occur. Recent recognition of the potential for a great earthquake (moment magnitude [M_W] 8+) rupturing the Cascadia subduction zone has also accelerated research into investigating crustal faults, which are the sources of the earthquakes occurring in the Portland region. Seismic monitoring of earthquakes in northern Oregon since 1980 has led to an improved understanding of seismogenic sources and the rate of earthquake occurrence in the region.

In this study, we have reviewed the earthquake history of the Portland region and reevaluated all events of approximate M_L 4 and greater that have occurred since the first recorded earthquake in 1846. Specifically, estimates of the magnitudes of these moderate-sized earthquakes were based on the size of their felt areas (i.e., areas in which the earthquake was reported as having been felt by people)—particularly, of course, those earthquakes that occurred prior to adequate seismographic coverage and thus do not have instrumentally determined values. After these reevaluated events have been incorporated into the historical record, the earthquake recurrence for the Portland region can be estimated. Such information is critical for the estimation of average recurrence intervals of earthquakes larger than the largest ever observed, e.g., M_L 6 and greater, and hence for the assessment of seismic hazards.

EARTHQUAKE DETECTION

How do we learn about earthquake occurrences? Historical earthquake records can generally be divided into records of the pre-instrumental period and the instrumental period. In the absence of adequate seismographic coverage, the detection of earthquakes is generally based on direct observations and felt reports. The results are strongly dependent on population density and distribution, and the study region, typical of much of the western United States, was sparsely populated in the 1800s. Thus the detection of pre-instrumental earthquakes shows varying degrees of completeness.

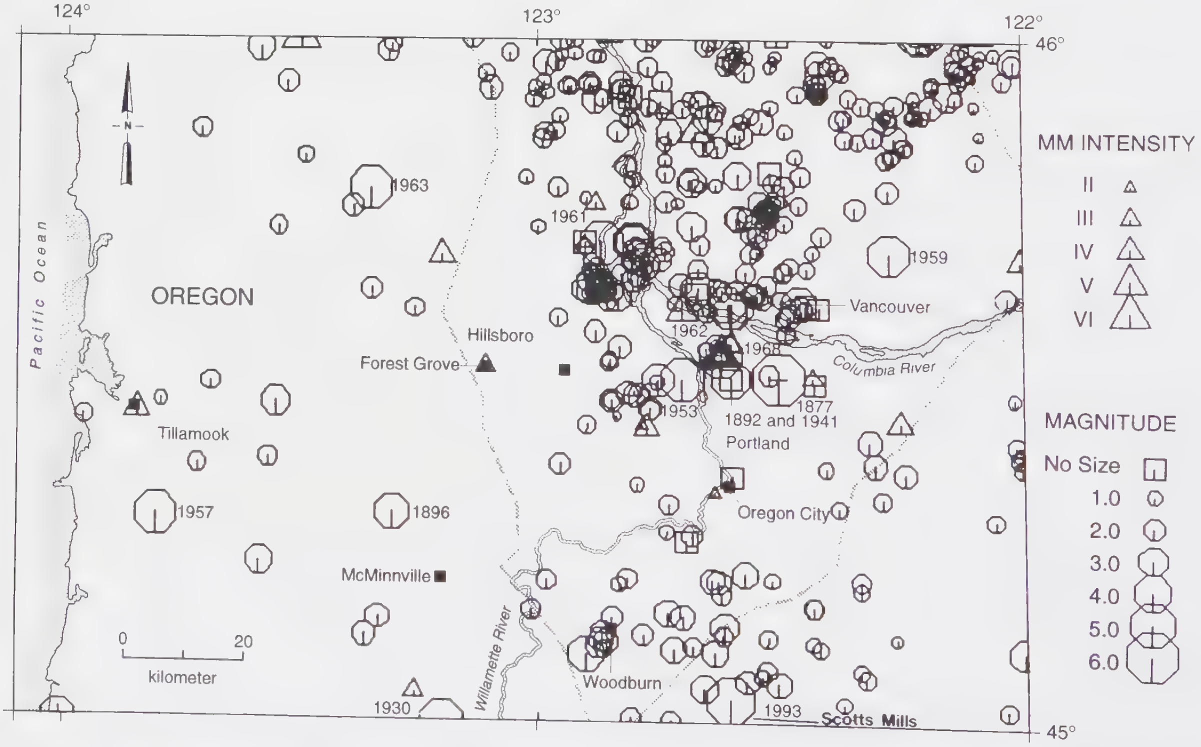


Figure 1. Historical seismicity of northwestern Oregon and portions of southwestern Washington during the period from 1846 to the present. In this study, the Portland region coincides with the Portland fold belt province as defined by Unruh and others (1993), and its boundaries are shown by the dashed line.

Table 1. *Types of earthquake magnitudes*

Symbol	Description
M_L	Richter (local) magnitude
M_S	Magnitude derived from recorded surface waves
m_b	Magnitude derived from recorded body waves
M_D	Magnitude derived from recorded duration of earthquake
M_W	Moment magnitude, derived from seismic moment
M	Unspecified magnitude

An evaluation of the population growth in the Portland region shows gradual increase up to 1940 in all counties except Multnomah (Oregon) and Pierce (Washington). Despite this slow growth, however, many widely distributed towns were established in or near the Willamette Valley and along the Columbia River as early as the 1850s. For example, Portland was first settled in the mid-1840s. Similarly, Salem was established in 1844, Hillsboro in 1845, Forest Grove in 1850, Eugene in 1852, McMinnville in 1853, and Tillamook in 1866 (Figure 1). Newspapers in the region, which are a major source of documentation, began publishing soon after the establishment of the major towns. Based on this relatively early settlement in the region, we estimate that the pre-instrumental historical record is complete for earthquakes of M_L 5 and larger since about 1850.

Although seismograph stations were established as early as 1906 in Seattle and 1944 in Corvallis, adequate seismographic coverage of the Portland region did not begin until 1980, when the University of Washington expanded its regional network into northwestern Oregon. Prior to this time, few stations operated in Oregon. Two of the most important seismograph stations, although at considerable distance from Portland, were the Blue Mountains Observatory in northeastern Oregon and the Longmire station in southwestern Washington. The latter was operated as part of the Worldwide Standardized Seismographic Network in addition to the Corvallis station. Based on this evolution of seismographic coverage, the historical record is complete at small magnitude levels (M_L 2.5 and greater) only since 1980.

SIGNIFICANT EARTHQUAKES

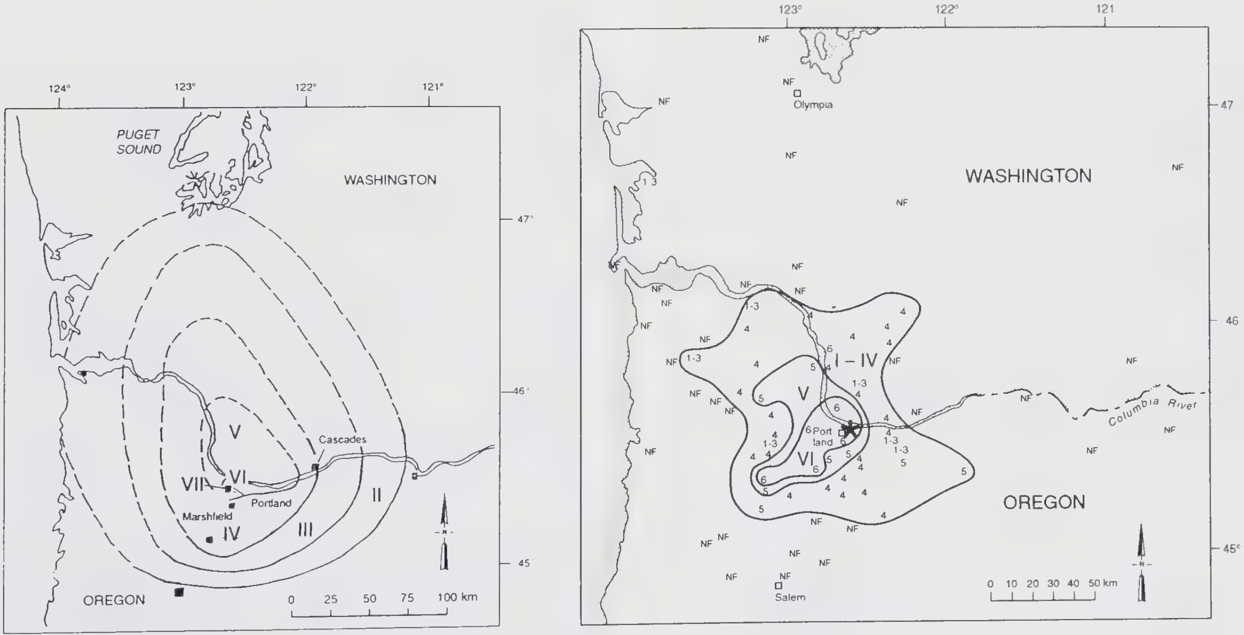
Introduction

In historical times, 17 earthquakes of estimated M_L 4 and greater are known to have occurred within the Portland region (Figure 1). These events, their felt effects and felt areas are described in the following discussion. Available isoseismal maps including ones developed in this study for the earthquakes in 1941, 1961 (August 18, September 17, and November 6), and 1963 were evaluated.

On the basis of several empirical relationships between felt areas of various intensities and M_L developed by Toppozada (1975) for California and western Nevada, we have attempted to estimate the magnitudes of the significant historical earthquakes in the Portland region. We believe that these relationships are applicable to both western Oregon and Washington because the crustal attenuation in both regions appears to be comparable to California. For example, the attenuation factor, Q_0, is about 150 in much of California and approximately 200 in northwestern Oregon and southwestern Washington (Singh and Herrmann, 1983). When we use the well-constrained felt areas of the 1962 Portland and the 1981 Elk Lake earthquakes for calibration, the Toppozada (1975) relationships appear to estimate the actual magnitudes quite well.

1877 earthquake

The earliest known significant historical earthquake in the Portland region occurred on October 12, 1877 (Figure 1). Two events are actually reported for this day, one at about 9 a.m. PST and one at 1:53 p.m. PST (Berg and Baker, 1963). There appears to be some confusion in the various anecdotal sources as to which event had a maximum intensity of Modified Mercalli (MM) VII (see Table 2 for description of MM intensity scale). Research by Thenhaus (1978) uncovered the fact that a smaller event of maximum intensity MM III occurred at 9 a.m. and was probably located near Cascades, Washington, because it was not reported as felt elsewhere. The second earthquake, at 1:53 p.m., occurred near Portland, where it caused chimneys to break (MM VII). It was also felt in a number of towns around Portland (e.g., Marshfield) and as far north as Puget Sound (Figure 2). Based on the isoseismal map developed by Thenhaus (1978), the total felt area is estimated to be 41,250 km^2.



Source Thenhaus (1978)

12 October 1877 M_L 4¾

29 December 1941 M_L 4½

Figure 2. Isoseismal maps for the 1877 and 1941 earthquakes. Asterisk indicates instrumentally determined epicenter.

Table 2. *Abridged Modified Mercalli (MM) intensity scale. Equivalent Rossi-Forel (RF) intensities in parentheses.*

I	Not felt except by a few under especially favorable circumstances. (RF I).
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (RF I to II).
III	Felt quite noticeably indoors, especially on upper floor of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (RF III).
IV	Felt indoors by many, outdoors by few during the day. Some awakened at night. Dishes, windows, door disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (RF IV to V).
V	Felt by nearly everyone, many awakened. Some dishes, windows, and other fragile objects broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (RF V to VI).
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (RF VI to VII).
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-Ebuilt ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (RF VIII).
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel wall thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water levels. Persons driving cars disturbed. (RF VIII + to IX).
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings; with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (RF IX +).
X	Some well-built structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (RF X).
XI	Few, if any, [masonry] structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

Averaging the estimated magnitudes from the various felt area relationships indicates that the 1877 earthquake probably was about a M_L 5¼ event (Table 3). For comparison, the M_L 5.5 Portland earthquake of 1962 was felt in Seattle with an intensity of MM IV, whereas the 1877 earthquake was felt only in the southern Puget Sound with an intensity of MM II. The less severe damage reported for the 1877 earthquake supports the conclusion that the 1877 earthquake had a smaller magnitude than the 1962 event.

1892 earthquake

At 8:30 p.m. PST on February 3, 1892, a "severe" earthquake (MM VI) (Townley and Allen, 1939) caused brick buildings to sway and windows to rattle in Portland, terrifying people inside (Holden, 1898) (Figure 1). The motion was reported as lasting 30 seconds and as being the most severe shock ever felt in Portland, although this is puzzling, given the observations of the 1877 event. As far as is known, no major damage occurred. In Astoria, the earthquake lasted 3 seconds, causing houses to shake. It was felt as a light shock as far west as the Yaquina Head lighthouse on the Oregon coast. The earthquake was felt over an area of more than 26,000 km^2 (Coffman and others, 1982), although no known isoseismal map has been developed. Based on this felt area, a poorly constrained value of a M_L 5 is estimated (Table 3).

1896 earthquake

The inhabitants of McMinnville were awakened at 3:17 a.m. PST on April 2, 1896, by an earthquake of maximum intensity MM VI, accompanied by a loud rumbling noise and followed by two or three distinct shocks in rapid succession (Townley and Allen, 1939). The earthquake was felt in Portland at about 3:20 a.m. PST as a single shock of brief duration and was also felt as far south as Salem. The earthquake was felt over an area of about 2,600 km^2 (Coffman and others, 1982) and is thought to have occurred close to McMinnville (Figure 1), which was the location of the greatest felt intensity (Berg and Baker, 1963). We estimate a M_L 4 for this earthquake, because we believe the felt area may be somewhat underestimated (Table 3).

1930 earthquake

On July 19, 1930, at 6:38 p.m. PST, an earthquake of intensity MM V–VI (Coffman and others, 1982) occurred near Perrydale, Oregon, a town about 20 km northwest of Salem (Figure 1). Plaster cracked and windows rattled at McCoy (Neumann and Bodle, 1932), and the roadbed was cracked 0.8 km west of Perrydale. A smaller foreshock occurred in the same area on July 8 at 12:30 p.m. PST but with a maximum intensity of only MM III. Although no felt area has been estimated for the larger earthquake, reports of localized damage indicate a magnitude of at least M_L 4 (Table 3).

1941 earthquake

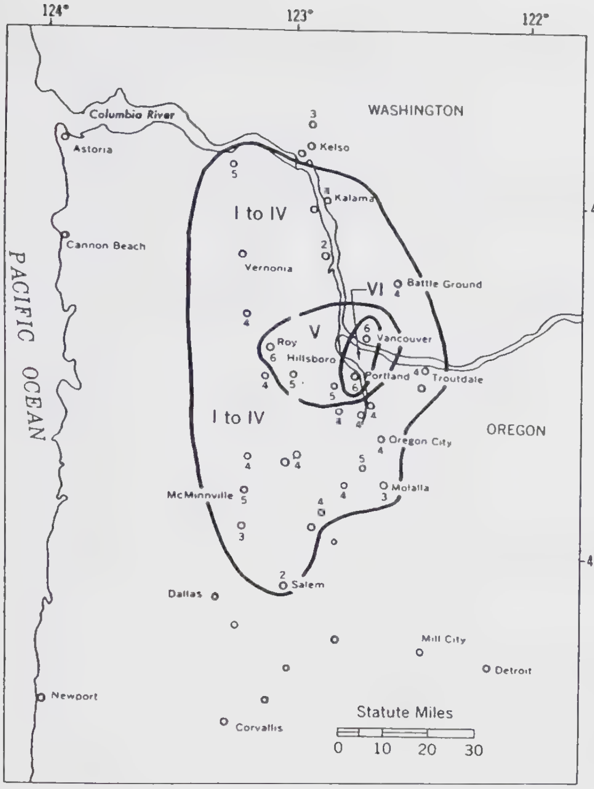
A strong earthquake was felt by most residents of Portland on December 29, 1941, at 10:37 a.m. PST (Figure 2). Small objects were displaced, and some trees and bushes were shaken (Neumann, 1943). Display windows shattered, and plaster cracked in Hillsboro and Sherwood. The earthquake caused chimneys to crack, vases to overturn, trees to shake and a school bell to ring in Yamhill, frightening many people (Neumann, 1943). Intensity MM VI effects were also felt in Vancouver and Woodland, Washington, where plaster cracked, vases overturned, and small objects moved. The felt area is estimated to be about 9,000 km^2, although this value is not well constrained. The epicenter is assigned to the Portland area, the location of the maximum intensity (Figure 1). Based on the size of the felt area, the earthquake appears to be about M_L 4½ (Table 3).

1953 earthquake

Coffman and others (1982) report that an earthquake of intensity MM VI occurred in northwest Oregon on December 15, 1953, and was felt over an area of about 8,000 km^2 (Figures 1 and 3). Slight damage was sustained in Portland and Roy, Oregon, and in Vancouver, Washington. The earthquake occurred sometime just before 8:32 p.m. PST on December 15, the time the earthquake was instrumentally recorded in Corvallis. In Portland, it was generally felt, frightening many people, cracking plaster, and causing objects and dishes to fall (Murphy and Cloud, 1955). Murphy and Cloud (1955) report one cracked chimney, slight damage to a tile fireplace, and cracks at the juncture between a one-story building and the abutting apartments. The location of this event is well constrained by the isoseismal map (Figure 3), which shows the maximum intensity within a small zone between Vancouver and Portland. Calculations of magnitude from the felt area suggest this earthquake to be about M_L 4½ (Table 3).

1957 earthquake

On November 16, 1957, at 10:00 p.m. PST, an earthquake shook the area just northwest of Salem (Brazee and Cloud, 1959) (Figure 4). The instrumental (i.e., instrumentally determined) location reported in Coffman and others (1982) lies about 80 km northwest of Salem, 60 km further west than the felt epicenter would suggest (Figure 1). This large discrepancy may be due to a



Source: Murphy and Cloud (1955)

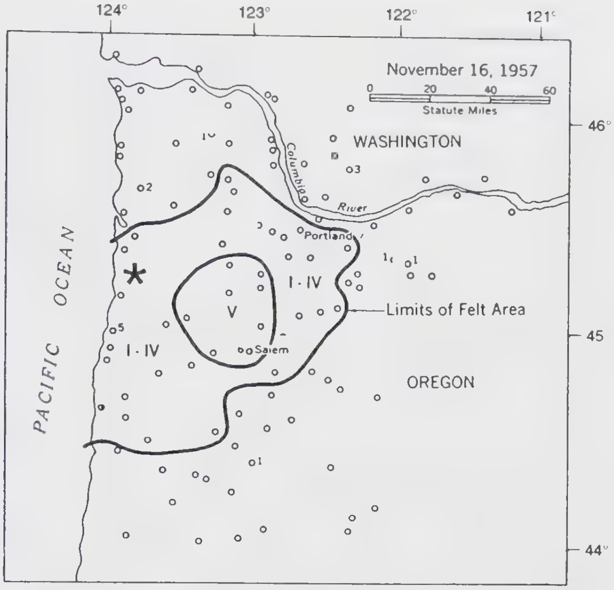
15 December 1953 M_L 4½

Figure 3. Isoseismal map for the 1953 earthquake.

bias in the population distribution or site-response effects in the Willamette Valley area around Salem. Similarly, strong ground shaking occurred in the Salem area in the recent Scotts Mills earthquake, as typified by the damage to the State Capitol building, although the epicenter lay about 32 km to the east. Most people in Salem were frightened by the 1957 earthquake, where the highest intensity is reported (MM VI) (Figure 4). However, only slight damage, consisting of cracked walls and plaster, was reported in the western part of Salem (Brazee and Cloud, 1959). Momentary power outages were reported, including a television blackout. Some people felt a single sharp, blast-like jolt, while others said the vibrations lasted for several seconds. The magnitude, based on the felt area of 13,600 km^2 assumed for this event (Figure 4), is estimated to be about M_L 4½ (Table 3).

August 18, 1961, earthquake

At 8:46 p.m. PST, on August 18, 1961, a maximum intensity MM VI earthquake was felt in and around the towns of Lebanon and Albany south of Salem (cover illustration). This earthquake was felt over an area of 18,300 km^2 from southwest Lane County in Oregon to Cowlitz County in Washington. The instrumental location is approximately 40 km northeast of the location of the maximum intensity (cover illustration), where chimneys toppled, windows broke, traffic lights and signs fell, and plaster cracked. The instrumental (i.e., instrumentally determined) magnitude assigned to this earthquake is M 4.5 (unspecified magnitude scale) by Cal Tech in Pasadena, California, and a coda duration magnitude (M_D) 3.9 as measured at the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993). The available data show a large felt area trending north-south, but the east-west extent is difficult to constrain. The magnitude of the event from limited felt information suggests a M_L 4½ (Table 3).



Source: Brazee and Cloud (1959)

16 November 1957 M_L 4½

Figure 4. Isoseismal maps for the 1957 earthquake. Asterisk indicates instrumentally determined epicenter.

September 15/17, 1961, earthquakes

Two moderate earthquakes occurred on September 15 and 17, 1962, approximately in the same vicinity near Siouxon Peak in southwestern Washington. The maximum intensities and felt areas are MM VI and 22,000 km^2, and MM VI and 24,300 km^2, respectively (cover illustration and Table 3). The first event occurred at 7:25 p.m. PST near Cougar, Washington, in Gifford Pinchot National Forest. The event was felt by and frightened many people, and the shock lasted 20 seconds. Small objects were overturned, and hanging objects swung east-west (Lander and Cloud, 1963). Several aftershocks that were felt followed the first event.

The September 17 earthquake, the larger of the two events, occurred at 7:56 a.m. PST. Instrumental magnitudes for the two principal earthquakes on September 15 and 17 are M_L 4.8 and M_L 5.1, respectively, determined from the Wood-Anderson seismograph operated by the University of California at Berkeley (UCB) in Arcata, California (Grant and Weaver, 1986) (Table 3). The epicenter of the larger event was southeast of Cougar (cover illustration), where the shaking lasted 20 seconds, and most observers felt it and heard moderate earthquake noises. A house shifted 2.5 cm on its foundations in North Bonneville, Washington. In Stevenson, Washington, there was slight damage to chimneys, cement foundations cracked, a woodstove moved 15 cm, and plate glass "rippled like a flag" (Lander and Cloud, 1963). In Latourell, Oregon, some cracks were found in a heavy cement basement foundation. Booming noises were heard at Yale Dam and Washougal, Washington. Grant and Weaver (1986) suggest that this earthquake occurred within the Mount St. Helens seismic zone.

November 6, 1961, earthquake

At 5:29 p.m. PST on November 6, 1961, an earthquake was widely felt over an area of 23,000 km^2 in northwest Oregon and southwest Washington (cover illustration). There is some uncertainty in the instrumental location of this earthquake. However, an aftershock of maximum intensity MM V on November 7 at 1:30 p.m. was felt principally in the Portland area, where china clinked, pictures tilted, and a television set slid across the floor. The location of the aftershock suggests that the main shock may have occurred closer to Portland than the instrumental locations would indicate (cover illustration and Figure 1).

During the main shock, minor cracking of plaster appeared to be the principal damage (Lander and Cloud, 1963). Some people reported that this event was the sharpest shock felt in Portland since the body-wave magnitude (m_b) 7.1 earthquake of April 13, 1949, that was centered around Olympia, caused $25 million in damage, and killed eight people. The 1961 earthquake caused a brick chimney to fall, plaster to crack, interior lights to break, door frames to jam, and a water fountain in Portland to spring a leak (Lander and Cloud, 1963). Groceries were thrown from shelves in a grocery store, and windows rippled. People reported noises from several directions. In nearby Glenwood, Washington County, the earthquake was felt by all in the community. Concrete foundation blocks broke, loud rumbling noises like a truck passing by were heard, and a porch roof under repair fell down (Lander and Cloud, 1963).

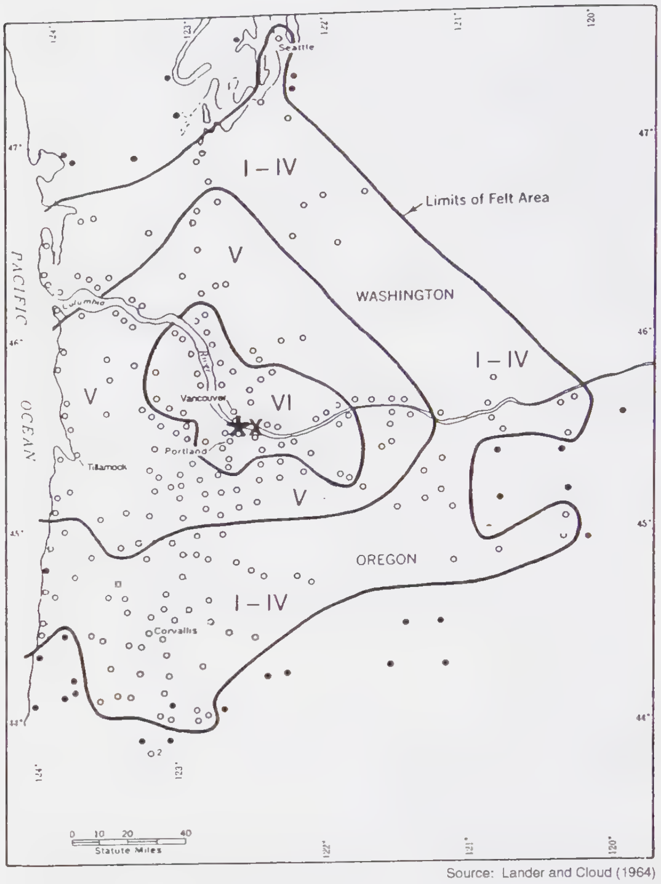
A magnitude of M_D 4.5 has been estimated from the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993); however, Grant and Weaver (1986) note that Longmire magnitudes tend to overestimate the actual value by several tenths of a magnitude unit. Based on the felt area, we estimate a M_L 5 for the 1961 event (Table 3).

1962 earthquake

Until the recent Scotts Mills earthquake, the largest event in historical times in the Portland region occurred at 7:36 p.m. PST on November 5, 1962, with a maximum intensity of MM VII (Coffman and others, 1982) (Figure 1). Numerous chimneys cracked or fell down, windows broke, and plaster cracked in Portland (Dehlinger and Berg, 1962). Six light fixtures fell in a grocery store, and the newsroom located on the fourth floor of the *Journal* Building sustained cracks (Lander and Cloud, 1964). No damage to utilities occurred, but the upsurge of telephone use after the earthquake caused a temporary disruption of service in some areas. A crack 7 m long and 4 cm wide appeared on a road between Tillamook and Oceanside, Oregon (Lander and Cloud, 1964). In Vancouver, Washington, a large chandelier fell, and a jail elevator was put out of service. Numerous aftershocks occurred, but none were large enough to be felt in Portland.

The magnitude of this earthquake has been variously estimated as M 4¾ (UCB-Berkeley, probably M_L), M_L 5 (Dehlinger and others, 1963), M_L 5½ (UCB-Arcata), and more recently as M_D 4.9 and M_L 5.2 (Yelin, 1990) and M_W 5.2 (Yelin and Patton, 1991) (Table 3). It was felt over a wide area (estimated as 52,400 km^2 from Coffman and others [1982] and 70,000 km^2 in this study) (Figure 5). Our magnitude estimate based on the felt area is M_L 5½ (Table 3). Peak ground accelerations of 0.076 *g* (vertical) and 0.103 *g and 0.096 g (horizontal) were measured at a the U.S. Coast and Geodetic Survey strong motion seismograph in the former State Office Building in downtown Portland (Dehlinger and others, 1963). Dehlinger and others (1963) located this event at a depth of 15–20 km, although this value is not well constrained.*

In a more recent study of earthquakes in the Portland area, Yelin and Patton (1991) relocated this event to 15 km northeast of downtown Portland, just east of the original epicentral location of Dehlinger and others (1963), and to a depth of 16 km (Figure 5).



Source: Lander and Cloud (1964)

5 November 1962 M_L 5.5

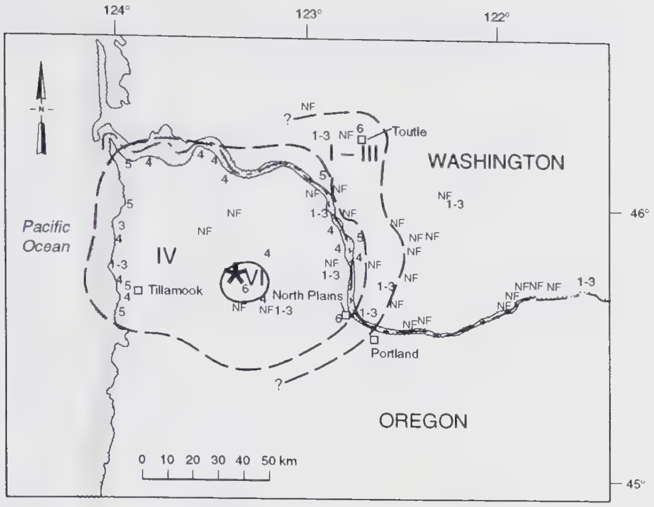
Figure 5. Isoseismal map for the 1962 earthquake. Asterisk indicates instrumentally determined epicenter.

1963 earthquake

At 6:36 p.m. PST on December 26, 1963, an earthquake was felt with a maximum intensity of MM VI in northwestern Oregon (von Hake and Cloud, 1965). This earthquake was felt over an area of only 10,700 km^2 (Figure 6), and damage was slight. Plaster cracked in a few places, and books and pictures fell in North Plains and Timber, Oregon, and Toutle, Washington. In Tillamook, Oregon, a car swayed and went to the opposite side of the highway before being controlled. The isoseismal map for this earthquake (Figure 6) is not well constrained due to differing intensity reports in closely spaced locations—possibly an indication that varied site conditions played a major role in ground motions. The instrumental location, however, agrees well with the area of maximum intensities northwest of Portland (Figures 1 and 6). A magnitude of M_D 4.1 (Longmire) and m_b 4.5 (NOAA) have been instrumentally determined (Table 3). The calculated magnitude from the felt area is M_L 4½.

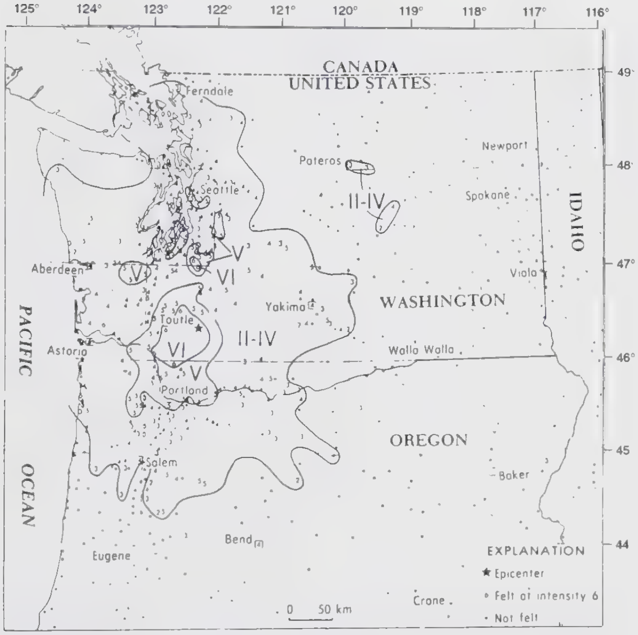
1981 earthquake

The 1981 Elk Lake, Washington, earthquake, the largest known earthquake associated with the St. Helens seismic zone, occurred at 10:09 p.m. PST on February 13, 1981. The earthquake, with magnitudes m_b 5.1, M_S (surface-wave magnitude) 4.8, M_L 5.5, and M_D 5.2 (Stover, 1984), was felt over an area of 104,000 km^2 (Figure 7 and Table 3). Maximum intensities of MM VI were felt around the epicentral region. Damage was reported as foundation and plaster cracks, overturned furniture, broken glasses and dishes, and a few cracked windows. In Ariel, the sidewalk cracked and in Graham, seiches (earthquake-generated waves) occurred in lakes and swimming pools, and chimneys were cracked (Stover, 1984). In Kidd Valley, pottery was broken and 300 maps fell to the floor in the Antique Shed store (Stover, 1984). The main shock was preceded nine months earlier by a swarm of earthquakes that occurred over a two-month period (Grant and others, 1984). The locations of about 1,000 aftershocks delineate a north-northwest-trending, right-lateral, strike-slip fault zone, 6 km long, 3 km wide, and extending from 5 to 12 km in depth (Grant and others, 1984). At least six aftershocks of M_L 2.9 to 3.6 were felt in Kidd Valley, 13 km east of Toutle, that night and the following day. The largest aftershock was felt as far south as Vancouver.



27 December 1963 M_D 5.0

Figure 6. Isoseismal map for the 1963 earthquake. Asterisk indicates instrumentally determined epicenter.



Source Stover 1984

13 February 1981 M_L 5.5

Figure 7. Isoseismal map for the 1981 earthquake.

Other significant earthquakes

Portland has been the site of several smaller earthquakes of interest. One earthquake occurred on January 27, 1968, at 12:28 a.m. PST, in the Portland area. This was the first large event since the damaging November 5, 1962, earthquake (Heinrichs and Pietrafesa, 1968). Heinrichs and Pietrafesa (1968) estimate the magnitude to be M_L 3.7 and the depth of focus to be at 20 to 24 km. Their epicenter places this earthquake south of the Columbia River in the eastern Portland area (Figure 1).

Another earthquake occurred on May 13, 1968, at 10:52 a.m. PST, and its epicenter is located between northeast Portland and the Columbia River. The instrumentally determined value of M_L 3.8 for the event is from the Blue Mountains Observatory. The focal depth is thought to be around 4–12 km (Couch and others, 1968), although it is not well constrained due to lack of adequate seismographic coverage. A maximum intensity of MM IV was felt in Portland. The earthquake caused windows to rattle and hanging objects to swing, but no damage was reported. This earthquake occurred in the vicinity of the November 5, 1962, and the January 27, 1968, events (Figure 1).

Other moderate-sized earthquakes in the Portland region include the following:

- A MM V on August 4, 1959, 21 km northeast of Portland (Figure 1), which was felt over an area of 1,570 km^2. In Portland, the event caused swaying motion, and a few objects were displaced (Eppley and Cloud, 1961). Based on the felt area, the magnitude for this earthquake, estimated to be M_L 4.7 by the Canadian seismographic network, appears to be significantly overestimated.
- A m_b 4.6 event on March 7, 1963, which occurred west of Salem but was felt from Portland to Eugene (von Hake and Cloud, 1965). Damage was limited to slightly cracked plaster and broken dishes in Salem.
- A M_D 3.5 (Longmire) earthquake on January 26, 1964, near Merrill Lake, Washington (von Hake and Cloud, 1966). The event was felt over an area of 5,000 km^2 but only made windows and dishes rattle.
- A M_D 4.1 (Longmire) (MM V) event on October 1, 1964, 9 km east of Cougar (von Hake and Cloud, 1966). Many people were awakened in Portland, and windows and doors rattled.
- A m_b 4.3 (MM V) event on November 30, 1968, in Lewis County, Washington, that was felt over an area of 2,600 km^2 (Coffman and Cloud, 1970).

EARTHQUAKE RECURRENCE

The recurrence or frequency of occurrence for earthquakes in a given magnitude range in a specific region can be estimated on the basis of the Gutenberg-Richter relationship developed for that region. We have estimated this relationship for the Portland region, using our revised historical earthquake record and following the maximum-likelihood procedure developed by Weichert (1980). The earthquake record was corrected for incompleteness, and dependent events (foreshocks and aftershocks) were deleted. All event magnitudes were converted to equivalent M_L values.

Assuming the usual form of the Gutenberg-Richter relationship of $\log N = a–bM$, the recurrence parameters of b and a of 0.84 ± 0.07 and 2.55, respectively, were estimated for the Portland region. This recurrence results in a return period for earthquakes of M_L 6 and greater of about 325 years, with the uncertainty in this value being at least several decades. For M_L 5.5 and greater, the return period of 100 to 150 years is consistent with the occurrence of the 1962 Portland and 1993 Scotts Mills earthquakes in the 150-year historical period. For M_L 6.5 and greater earthquakes, the return period is estimated to be approximately 800–900 years.

CONCLUSIONS

In the relatively brief historical record for northwestern Oregon and southwestern Washington, a large number of moderate-sized earthquakes up to M_L 5.6 have shaken the Portland region and sometimes caused damage. In view of the tectonic and geologic setting of the Portland region astride the Cascadia subduction zone, however, the occurrence of earthquakes as large as M_L 6½ or larger, which have not been experienced in historic times, also seems quite possible. The historical record suggests that such events may occur in the Portland region every few hundred years. It would seem prudent that residents as well as the engineering community and government agencies take the proper steps to mitigate the hazards that will be posed by such probably damaging earthquakes.

Table 3. *Significant historical earthquakes in the Portland region, showing areas for three MM intensity zones ($A_{I\text{-}V\text{-}VI}$), magnitudes calculated from each area (M_{A_I}, etc.), average (M_{ave}), and best estimate (M_{FA}) magnitudes. Recording source abbreviations: UCB = University of California-Berkeley; UW = University of Washington; NOAA = National Oceanic and Atmospheric Administration*

Earthquake	Maximum intensity	A_I (km^2)	A_V (km^2)	A_{VI} (km^2)	M_{A_I}	M_{A_V}	$M_{A_{VI}}$	M_{ave}	M_{FA}	Instrumental magnitude (recording station or source)
October 12, 1877	VII	41,250	2,875	125	5.2	4.6	4.3	4.7	5¼	—
February 3, 1892	V-VI	26,000	—	—	4.9	—	—	—	5	—
April 2, 1896	V	2,600	—	—	3.3	—	—	—	4	—
July 19, 1930	V-VI	—	—	—	—	—	—	—	4	—
December 29, 1941	VI	9,300*	2,143	803	4.2	4.5	5.0	4.6	4½	—
December 15, 1953	VI	10,000	1,782	341	4.3	4.4	4.7	4.5	4½	—
November 16, 1957	VI	13,600	2,476	—	4.5	4.6	—	4.55	4½	—
August 18, 1961	VI	18,300	—	—	4.6	—	—	4.6	4½	M 4.5 (Pasadena); M_D 3.9 (Longmire).
September 15, 1961	VI	22,000	3,213	—	4.8	4.7	—	4.75	4¾	M_L 4.8 (UCB-Arcata).
September 17, 1961	VI	24,300	5,125	—	4.8	4.9	—	4.85	5	M_L 5.1 (UCB-Arcata).
November 6, 1961	VI	23,000	5,656	919	4.8	5.0	5.1	5.0	5	M_D 4.5 (Longmire).
November 5, 1962	VII	70,000	29,403	6,790	5.4	5.7	5.8	5.6	5½	M_W 5.2 (Yelin and Patton, 1991); M_L 5.0 (Dehlinger and others, 1963); M_L 5.5 (UCB-Arcata).
December 26, 1963	VI	10,700	—	—	4.3	—	—	4.65	4½	M_D 4.1 (Longmire); m_b 4.5 (NOAA).
February 14, 1981	VI	104,000	15,800	1,900	5.8	5.4	5.3	5.5	5½	M_L 5.5, M_D 5.2 (UW); M_S 4.8 , m_b 5.1 (Stover, 1984).

*Felt area estimate not well constrained

ACKNOWLEDGMENTS

This study was supported by the U.S. Bureau of Reclamation under contract No. 1–CS–81–16240. Our gratitude to Jon Ake and Fred Hawkins of the Bureau for their assistance. The government does not necessarily concur with the conclusions or results of the study or endorse this publication. Thanks to Jeff Unruh, Sue Penn, and Fumiko Goss for their assistance. Reviews by Ian Madin and Tom Yelin are appreciated. Our appreciation to Tom Yelin for providing unpublished duration magnitudes from the Longmire station.

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To our readers

Because of the length of the articles, this issue has been expanded from the usual 24 pages to 28 pages. As a result, we shall publish one of our later issues with 20 pages.

—ed.

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The ORE BIN
Volume 34, no. 11
November 1972

COASTAL LANDFORMS
BETWEEN TILLAMOOK BAY AND THE COLUMBIA RIVER, OREGON

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The 50-mile stretch of the Oregon coast between Tillamook Bay and the Columbia River can be divided into three nearly equal segments according to the kinds of landforms along them. The southern segment extends from Tillamook Bay to Neahkahnie Mountain (map 1), the middle from Neahkahnie Mountain to Tillamook Head inclusive (map 2), and the northern from Tillamook Head to the Columbia River (map 3). The discussion of the landforms is presented in the order of these divisions.

In preparing this article, an attempt was made to use as few technical terms as possible in view of the fact that many of The ORE BIN readers may not have had formal education in the earth sciences. It is not possible, however, to avoid all technical terms in a presentation such as this; therefore, a glossary of words most likely to be troublesome is available at the end of the article.

Tertiary Bedrock and its Role in Landform Development

Bedrock along this part of the Oregon coast consists of marine sedimentary strata of Oligocene to mid-Miocene age and Miocene basalt of intrusive and extrusive varieties. The sedimentary rocks have been subdivided by Schlicker and others (1972) into two parts: unnamed strata of Oligocene to mid-Miocene age and the middle Miocene Astoria Formation as redefined. Miocene sedimentary rocks and basalt are in part contemporaneous, and in places the two are interbedded (Snavely and Wagner, 1963). Their distribution is the main factor in the development of the shore's configuration and of the landforms along it.

Marine sedimentary rocks

Many of the coastal exposures consist of sedimentary strata assigned to the Astoria Formation. The deposits were probably laid down in shallow marine embayments along the western margin of Oregon during middle Miocene time after the Coast Range uplift had begun. Beds vary from place to place in rock type but consist mainly of olive-gray sandstone and dark-gray siltstone and shale. There are also beds of yellowish-gray, water-laid volcanic ash that range from a few inches to 18 feet in thickness, and because the ash is similar in composition to ash of the same age in the western Cascades, it is believed to have come from eruptions in an ancestral Cascade Range (Snavely, Rau, and Wagner, 1964). In comparison to the basalt, the sedimentary rock is weak in its ability to withstand erosion, and it is in this rock that the coves, bays, and other re-entrants along this part of the coast are formed.

Basalt

At the time lava was pouring out of the earth to form the Columbia River Basalt in the Columbia River Gorge and the basalt layers of the Columbia Plateau, basalt lava was erupting from vents near the present shoreline. Some of the basalt erupted under the sea, or poured into it, where it became complexly intermixed with the sediment on the sea floor. The rock of these flows is usually fragmental in contrast to the more homogeneous, dense rock that poured out on land. Associated with the flows are intrusions, mainly dikes and sills, that solidified at shallow depth beneath the earth's surface. The rock of the smaller intrusions is fine grained and dense, but in the larger ones the grain size is coarse enough that individual mineral grains are readily discernable. Some is sufficiently coarse to be classed as gabbro, the coarse-grained equivalent of basalt.

Basalt was once continuous over a large area along the northern part of the Oregon coast and inland from it and probably was continuous with basalt of the Columbia River Gorge and the Columbia Plateau. Only remnants, mainly at or near centers of eruption, are left, and where they are located along the shore, they form the prominent headlands and points and the reefs, stacks, and arches just offshore from them.

Differences in hardness of the basalt from place to place and fractures and shear zones cutting through it have contributed to different rates of erosion, and differential erosion accounts for the variety of forms developed on basalt along the shore and offshore. Masses of hard rock surrounded by less resistant rock get isolated from the mainland by wave erosion to form the stacks and arches. The aligned rock reefs are remnants of what was once mainland. Trenches are cut into the basalt where it has been fractured, and caves penetrate the sea cliff along fractures or where a weak layer is exposed within reach of the waves. The irregularity of a given rock mass is a function of the rate at which its parts get removed by erosion, the attack of the waves being guided by the weak places.

Quaternary Deposits

Terrace deposits

Terraces are not as prevalent along this part of the Oregon coast as they are along the central and southern parts. However, in a number of places terrace sand and gravel are preserved over a wave-cut bench of Pleistocene age. The terrace was eroded into the marine sedimentary rocks at a time when sea level stood higher relative to the land than it does now. In places the terrace deposits are covered by sand dunes, and the bench form of the terrace is obscured.

Dune sand

Dunes are extensive in the southern and northern segments, where they occupy the lowland areas underlain by marine sedimentary bedrock. Sea cliffs along the shore of the middle segment have prevented dune development there, except at the mouth of Elk (Ecola) Creek. The complicated cross bedding seen in some road cuts through dunes is the diagnostic feature that distinguishes dune sand from the horizontally bedded terrace sand.

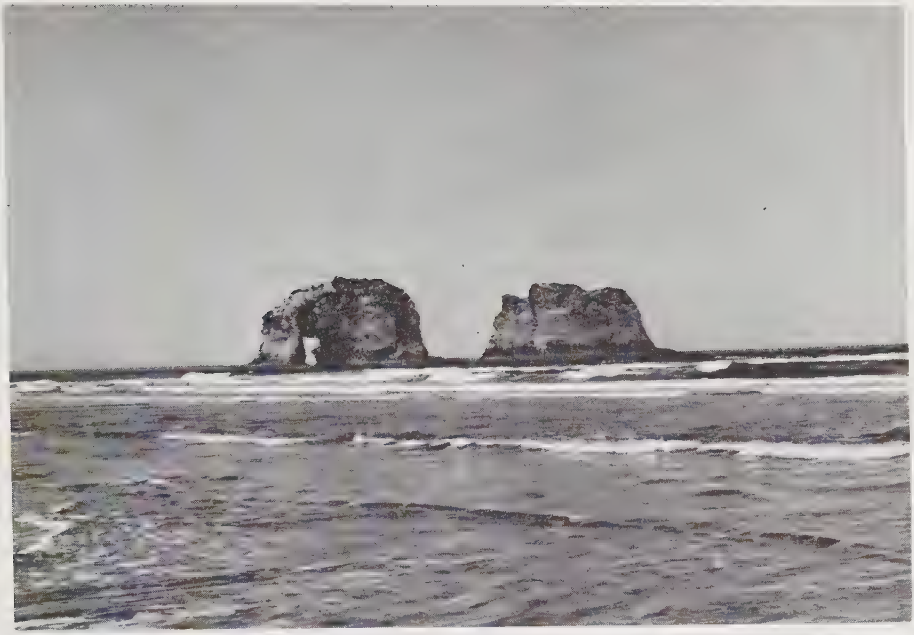


Figure 1. Twin Rocks are offshore remnants of basalt. The one at the left is an arch and the other a stack.

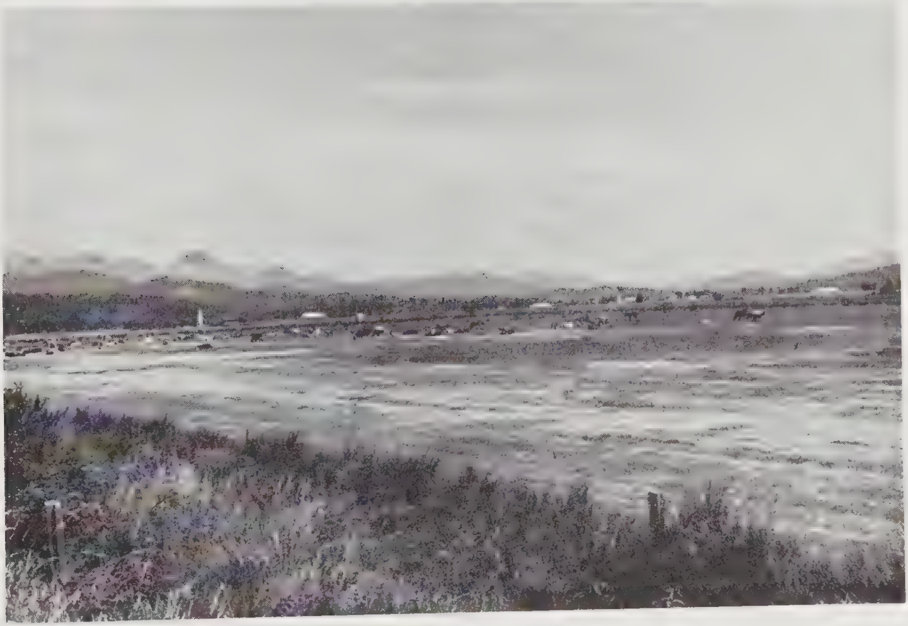


Figure 2. Alluvial plain of Nehalem River formed during the Pleistocene at a time of higher sea level.

Alluvium

Deep alluvial deposits are extensive along the major streams and around the bays. Sand, silt, and mud are presently being deposited by streams, especially at their lower ends where their flow is checked by tidal currents. Much of the sediment, however, was laid down at times during the Quaternary when the condition of flooding was promoted by higher sea levels.

Landforms

Southern segment (map 1)

The shore from Tillamook Bay to the base of Neahkahnie Mountain is bordered by a sand beach that is continuous except where it is interrupted by the Nehalem River. Aside from some very small areas of basalt that lie back from the beach and Twin Rocks that lie just offshore opposite the Twin Rocks community, the area is underlain by marine sedimentary strata.

At the southern end is Tillamook Bay, a large bay lying behind a sand peninsula that projects northward from Cape Meares. The water body is shallow over most of its extent, and it covers only about a fourth of the area once occupied by water in a Pleistocene embayment. The other three-fourths has been filled by bay sediment and river alluvium laid down by the Tillamook, Trask, Wilson, Kilchis, and Miami Rivers and smaller streams that flow into the bay.

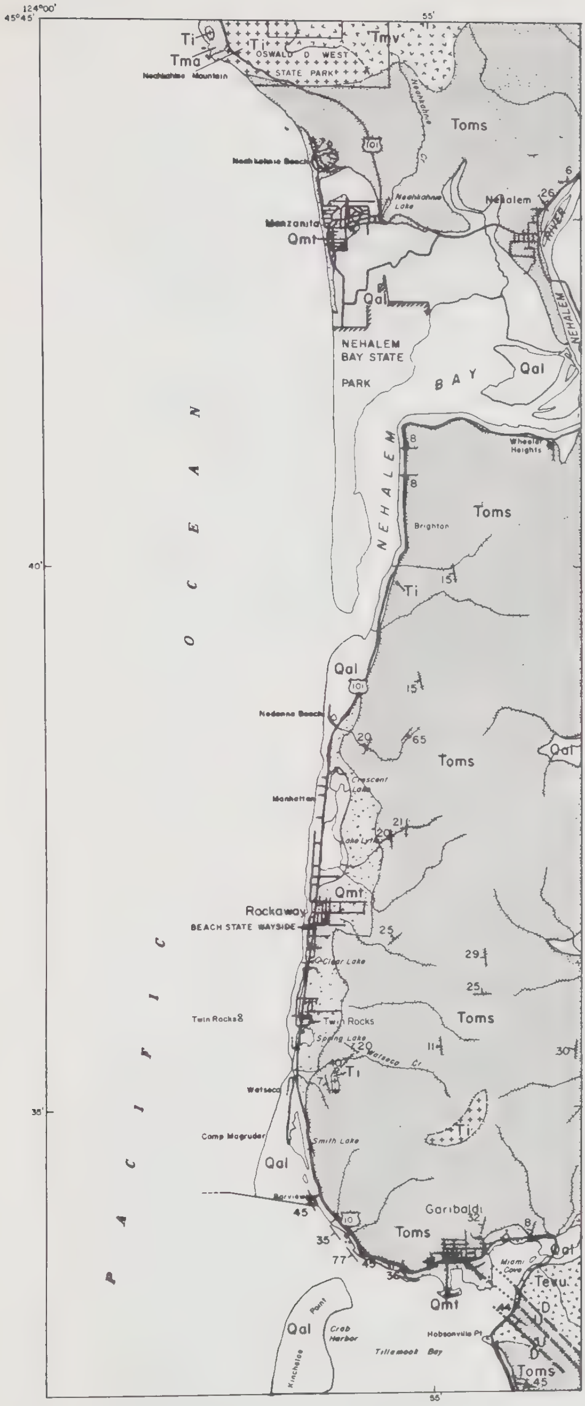
Small sea stacks and an arch just inside the bay about three-quarters of a mile east of Barview were formed when waves of the open ocean washed this part of the bay shore. These stacks are unusual in that they are composed of sedimentary rock.

Between Tillamook Bay and the mouth of Nehalem Bay is a narrow strip of coastal plain that is on a low bench cut on marine sedimentary rock. The western edge of the strip is occupied by dunes that begin in a dune complex just north of the outlet of Tillamook Bay and continue in a dune ridge that extends northward just behind the shore. A low, relatively level terrace surface lies between the dune ridge and the upland. Small lakes, the largest of which are Smith Lake, Crescent Lake, and Lake Lytle, are impounded by the dunes.

Two basalt remnants, Twin Rocks (Figure 1), lie a few hundred feet off the Beach at the Community of Twin Rocks south of Rockaway. One of them is a sea stack and the other is an arch.

At its north end, the narrow coastal plain strip is terminated by Nehalem Bay, the estuary of Nehalem River. As with Tillamook Bay, Nehalem Bay occupies only a fraction of the area of an earlier Pleistocene embayment. Bay filling and deposition of alluvium by the Nehalem River have formed an alluvial plain that extends inland along the river for nearly 10 miles (Figure 2). The fertile alluvial plains around several bays, including Tillamook and Nehalem, and along the many coastal streams support the Tillamook County dairy industry, which produces world-famous Tillamook cheese.

Projecting southward in front of Nehalem Bay is a long sand peninsula, a sandspit, that deflects the flow of the Nehalem River southward 2½ miles from the main body of the bay (Figure 3). Sandspits such as this have formed at the mouths of bays all along the Oregon coast. Some project northward and others southward, the direction being determined mainly by whether they are influenced more by the northward



MAP 1

Tillamook Bay to Neahkahnie Mountain

EXPLANATION

Qal — Alluvium and dune sand

Qmt — Marine terraces

UNCONFORMITY

Tmv — Miocene volcanic rocks
Localized accumulations of massive basalt breccia, basalt flows, palagonitic breccias and pillow basalts

Ti — Intrusive rocks
Middle to late Miocene basaltic intrusive rocks which include thick sills

UNCONFORMITY

Toms — Oligocene to Miocene sedimentary rocks
Over 5,000 feet of thin-bedded to massive, medium-gray to dark-gray, tuffaceous siltstone and claystone with subordinate amounts of sandstone and shale locally

UNCONFORMITY

Tevu — Undifferentiated Eocene volcanic rocks
Several thousand feet of chloritized basalt flows and basalt breccias of submarine and subaerial origin

U D — Faults
Dashed where approximately located or indefinite, dotted where concealed
U, upthrown side; D, downthrown side

——— - - - Contacts
Dashed where approximately located

45 — Approximate strike and dip of beds or flow

Active landslide

Scale in Miles

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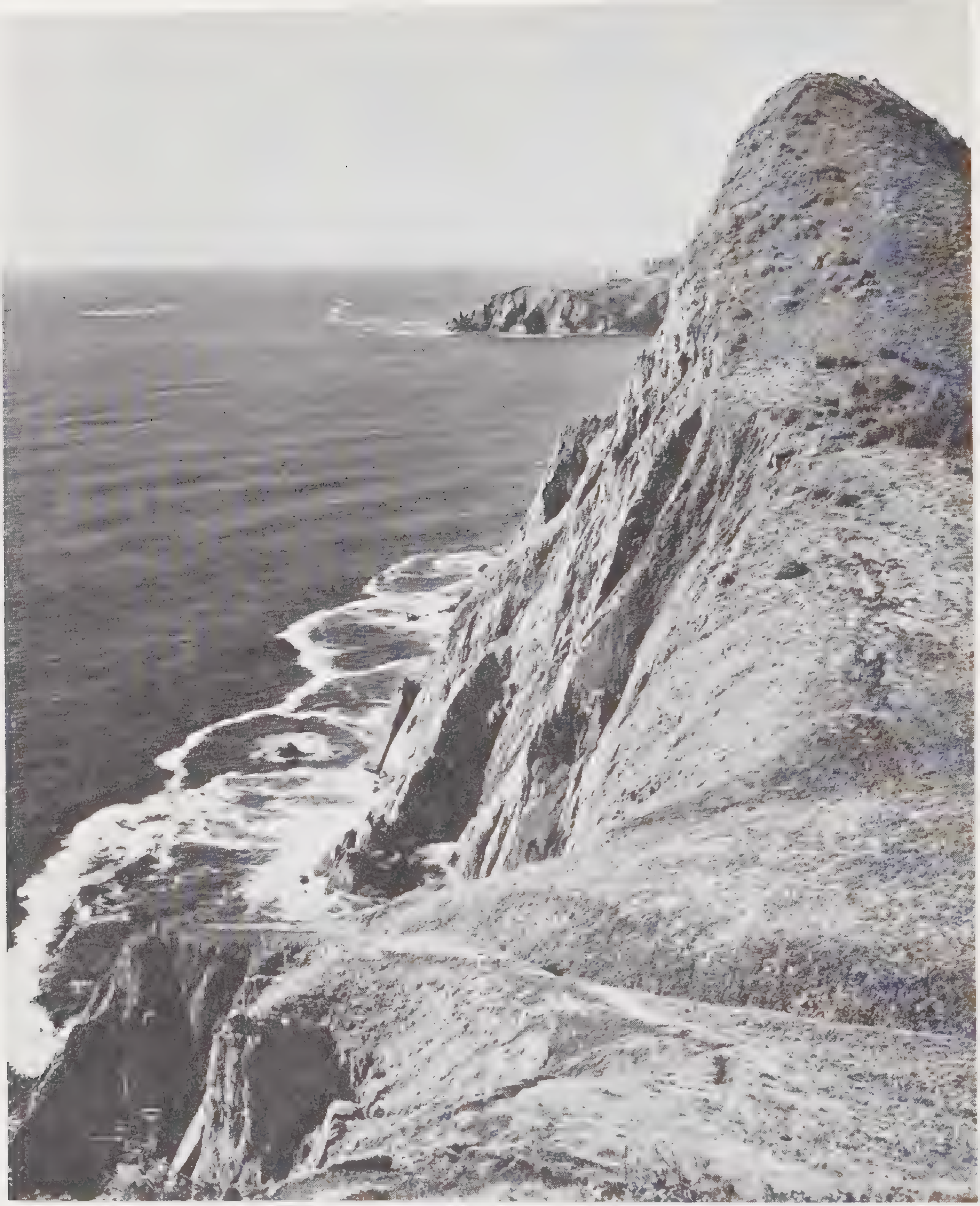
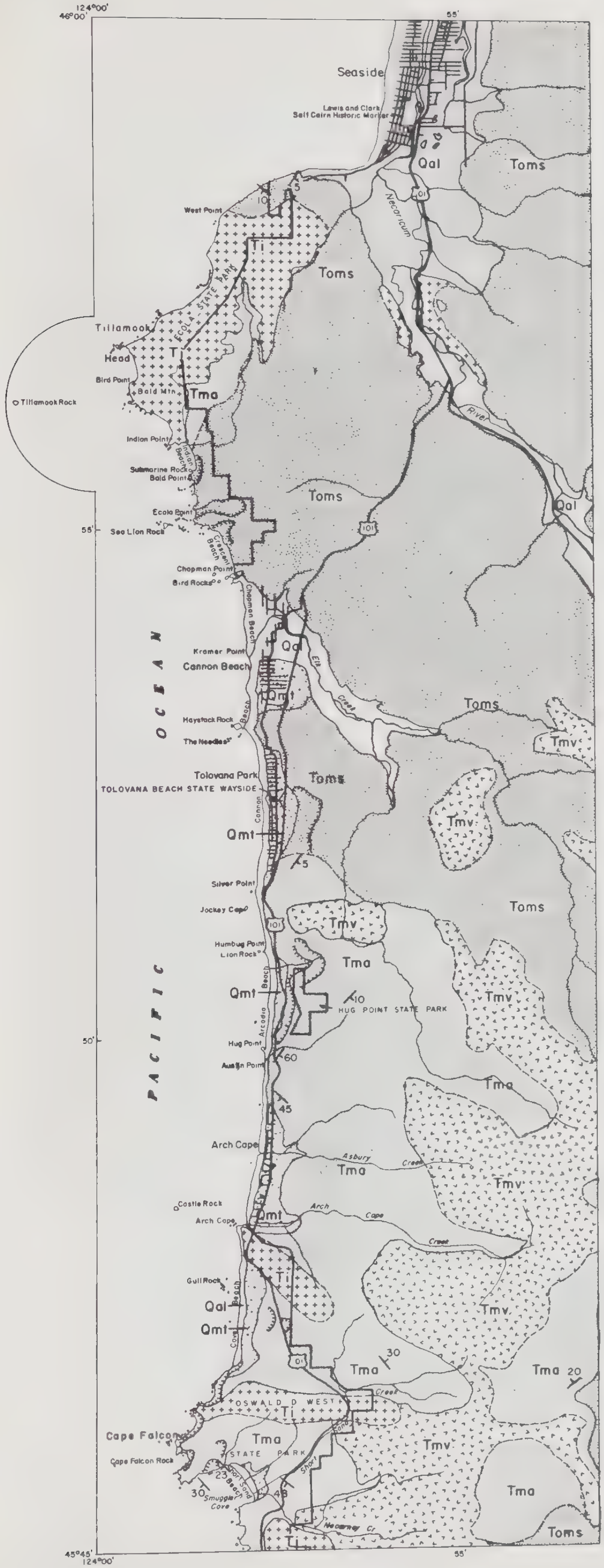


Figure 5. Cliff face on Neahkahnie Mountain. Cape Falcon is in the distance, and Smuggler Cove lies between these promontories. (Oregon State Highway Div. photo)

MAP 2

Neahkahnie Mountain to Tillamook Head



EXPLANATION

Qal Alluvium and dune sand

Qmt Marine terraces

UNCONFORMITY

Tmv Miocene volcanic rocks
Localized accumulations of massive basalt breccia, basalt flows, palagonitic breccias and pillow basalts

Ti Intrusive rocks
Middle to late Miocene basaltic intrusive rocks which include thick sills

Tma Astoria Formation
Approximately 2,000 feet of consolidated to semi-consolidated, thick-bedded to thin-bedded, medium-grained, buff, micaceous, arkosic sandstone and interbedded siltstone of early Miocene age

UNCONFORMITY

Toms Oligocene to Miocene sedimentary rocks
Over 5,000 feet of thin-bedded to massive, medium-gray to dark-gray, tuffaceous siltstone and claystone with subordinate amounts of sandstone and shale locally

╲ U D Faults
Dashed where approximately located or indefinite, dotted where concealed
U, upthrown side; D, downthrown side

— — Contacts
Dashed where approximately located

⊥45 Approximate strike and dip of beds or flow

⌒ Active landslide

Scale in Miles

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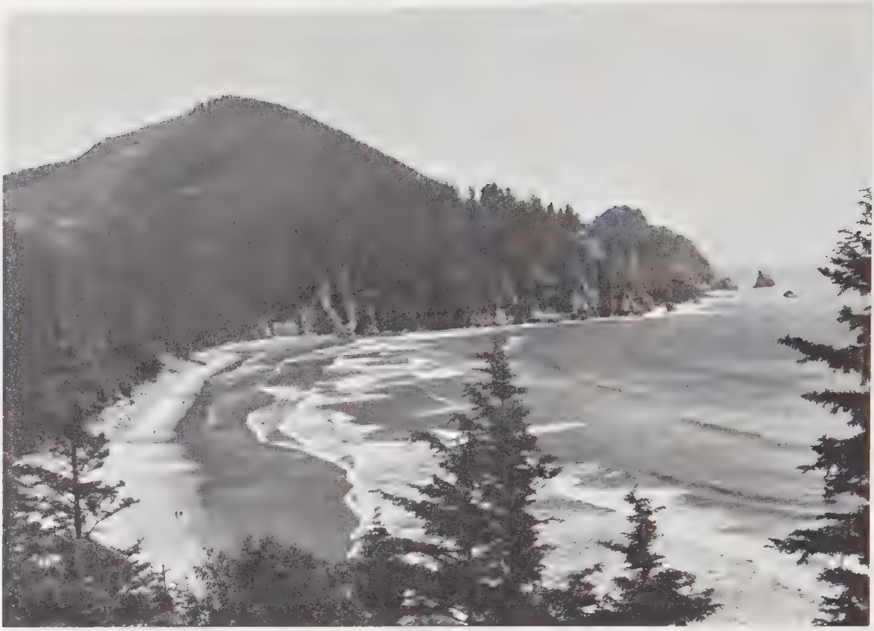


Figure 6. Short Sand Beach and Smuggler Cove. The rock behind the beach and flanking Neahkahnie Mountain on the north is sedimentary.

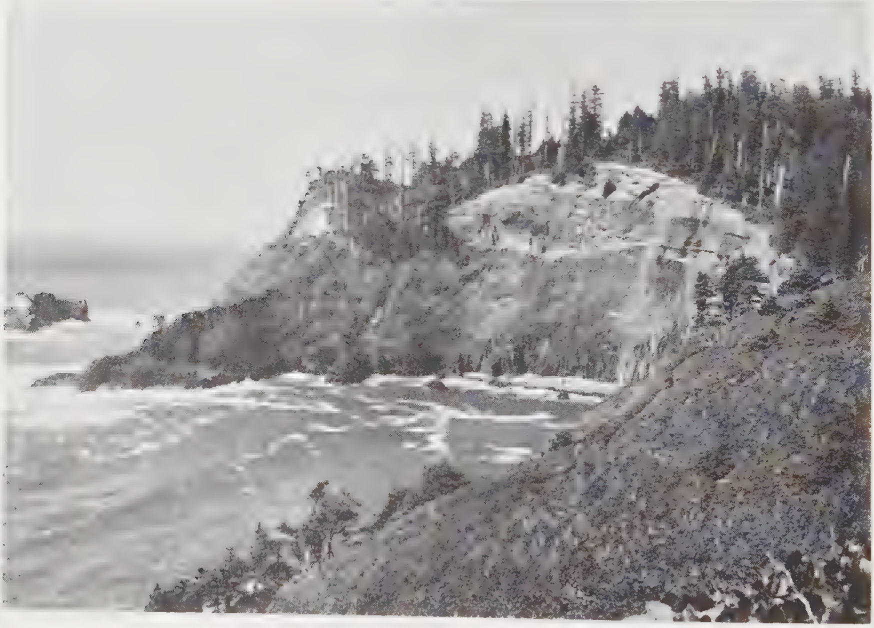


Figure 7. Small cove between two points of land on Cape Falcon. The rock in the sea cliff is intrusive basalt overlain by sedimentary beds.

Lying between Neahkahnie Mountain and Cape Falcon to the north is Smuggler Cove with Short Sand Beach (Figure 6) at its head. The cove is in the Astoria Formation, which forms sea cliffs on both the north and south sides and behind Short Sand Beach. Several small streams flow into the cove. Where Short Sand Creek and Necarney Creek enter it at the south end of the beach, there is a small area of low terrace on which camping and picnic facilities have been built. The water in the cove is sufficiently deep to be used by small craft when the open ocean gets rough. The configuration of the cove gives protection against the strong northwest winds of summer.

Cape Falcon is a headland comprising two points separated by a very small cove. Like the other headlands along this part of the coast, Cape Falcon is composed principally of basalt, but the southernmost point, the one bordering Smuggler Cove, is mainly sedimentary rock. This appears to be an anomolous condition but is explained by the presence of basalt beneath the sedimentary rock. Basalt forms the northern point and is exposed beneath sedimentary rock in the sea cliff around the small cove between the two points (Figure 7). The basalt is a sill-like body which is inclined toward the south at such an angle that, although exposed in the cove, it is below the water's surface on the south side of the southern point. Here a very hard layer of sandstone, further hardened by the intrusion of the basalt beneath it, is at the water's edge and offers unusual resistance to erosion. The basalt, however, gives the main support to the point. Several shallow caves have been cut along fractures in the basalt on the south side of the small cove between the two points, and a tunnel, visible from the highway, passes through the tip of the point bordering Smuggler Cove.

Neahkahnie Mountain and Cape Falcon are parts of a headland complex that extends northward to Arch Cape and lies at the southern end of an extensive area of basalt that forms a mountainous terrain inland. Sedimentary rock is interspersed with basaltic rock, and coves with sand beaches at their heads are developed where belts of the sedimentary rock are sufficiently wide. Short Sand Beach and Cove Beach are examples of sandy coves cut into sedimentary rock in a dominantly igneous terrain.

From Arch Cape to the promontories of Tillamook Head, the bedrock is almost continuously sedimentary and the land is low. The lowland area is level where there is a terrace and irregular where ridges of the hills to the east project to the shore. Elk (Ecola) Creek has removed the terrace and formed an alluvial plain at the northern end of the lowland, and the business section of Cannon Beach is built on this plain. North of the city a prominent dune, Pompadour Ridge, lies between the beach and the alluvial plain.

The shore in front of the lowland is sand beach interrupted here and there by small points of land supported by basalt and in some places massive sandstone. One of the breaks in the continuity of the beach is at Hug Point, a cluster of small promontories and intervening short beaches (Figure 8). North of Silver Point, Cannon Beach extends without interruption as far as Chapman Point. The beach segment between Elk Creek and Chapman Point is sometimes referred to as Chapman Beach.

Besides the several small promontories of basalt along the shore, numerous basalt remnants in the form of rock knobs and sea stacks lie just off shore. The most notable of these is Haystack Rock (Figure 9). This stack is principally fragmental basalt cut by numerous dikes. Near its base and in the satellite stack attached to the south side there is sedimentary rock intermixed with the basalt, which suggests the rock is of submarine origin or of lava that poured into the sea. Haystack Rock can be reached at low tide by a strip of sand, a tombolo, that extends to it from the beach.

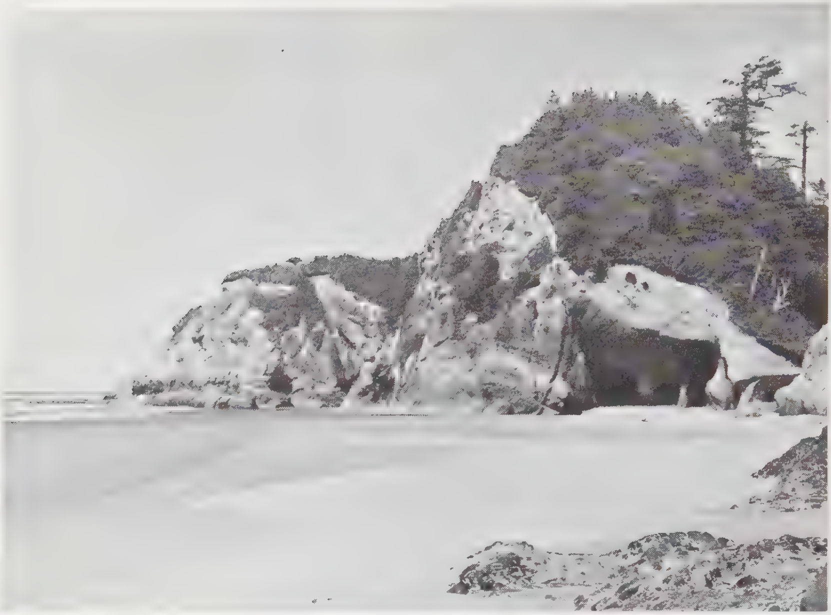


Figure 8. Beach and promontory at Hug Point State Park. The rock at this locality is mixed basalt and sediment and contains numerous sea caves, mostly in sedimentary rock. (Oregon State Highway Div. photo)

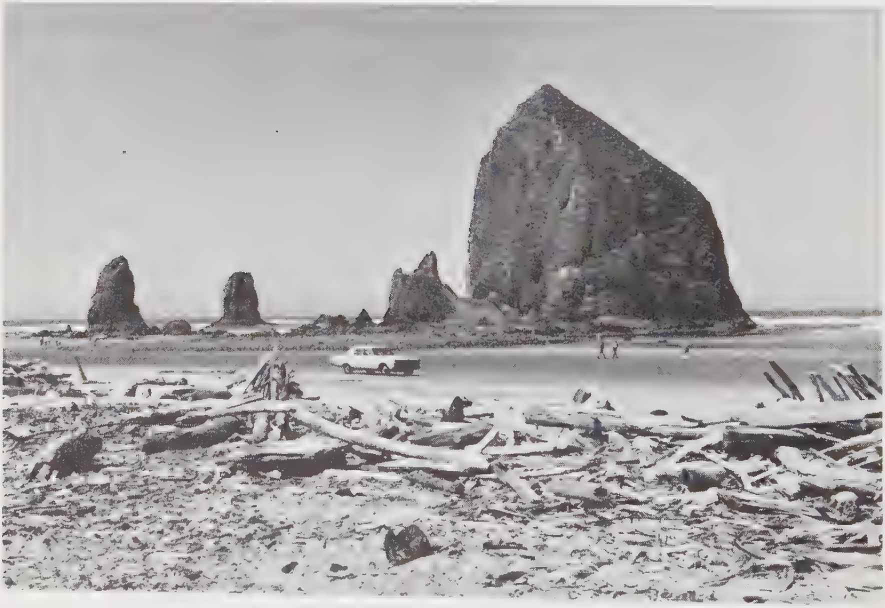


Figure 9. Haystack Rock is mainly of fragmented basalt. At its base and in the small "satellite" stack next to it, sedimentary rock is intermixed with the basalt.

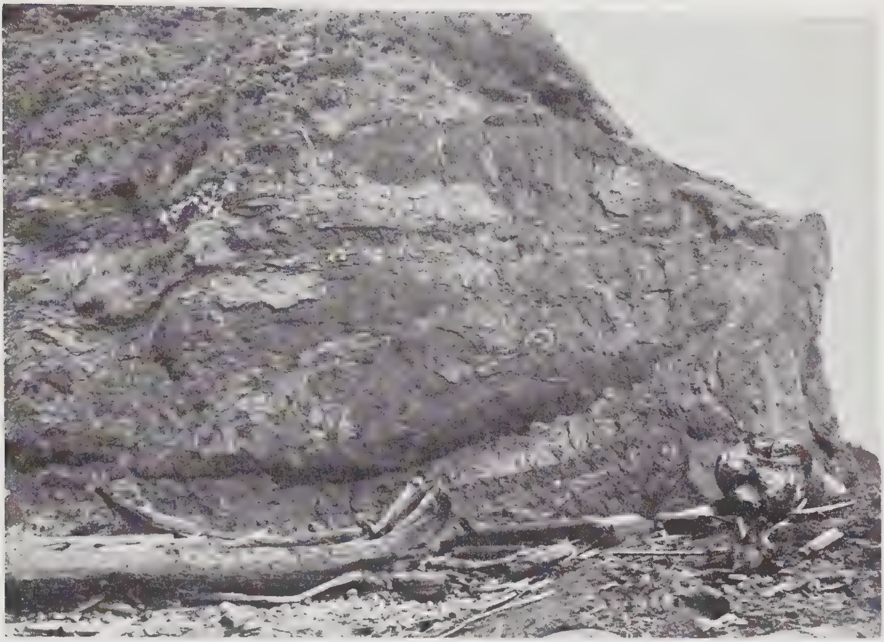


Figure 10. Interlayered basalt and sedimentary rock at Crescent Beach. The light bands are the sediment.

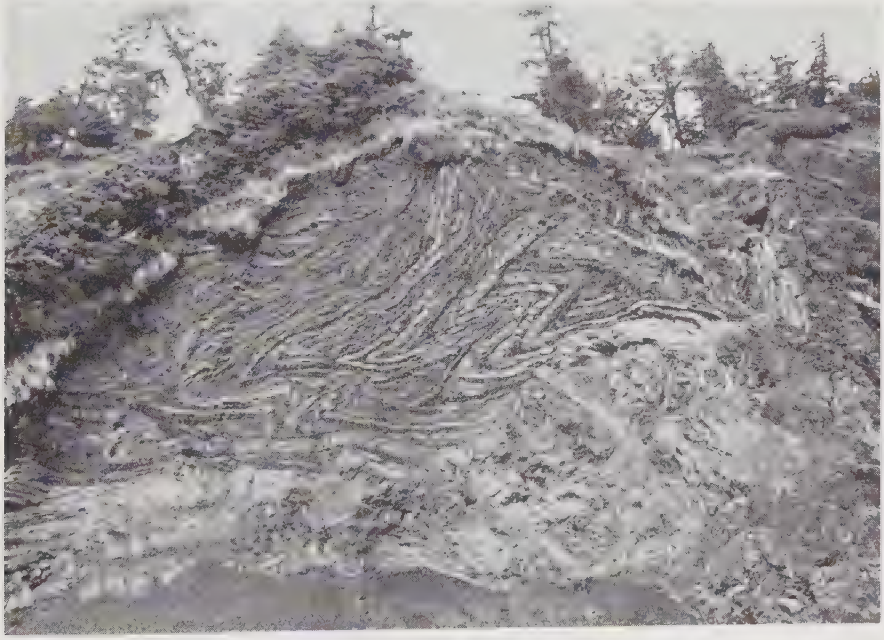


Figure 11. Contorted folding in sedimentary strata at the north end of Crescent Beach. This complex folding is probably the result of slumping in the sediment brought on by volcanic activity. A sill-like body of basalt lies at the base of the folded beds.

North of Cannon Beach is Tillamook Head, a complex of bold headlands, points of land, and intervening coves and shallow indentations. The main rock of this area is basalt, but in places basalt is complexly intermixed with sedimentary rock. Most of the basalt was emplaced as flows of both dense and fragmental varieties, and sedimentary beds are interlayered with basalt flows (Figure 10). Numerous basalt dikes and sills intruded the sedimentary strata.

The igneous activity, both intrusions and submarine flows, disturbed the sedimentary strata (Figure 11), which was not yet consolidated into firm rock, and unstable zones were formed in the rock masses. Where unstable zones are exposed to wave erosion, they are sites of landslides. Slides have been particularly active south of Tillamook Head between Chapman Point and Indian Point and are described by Schlicker, Corcoran, and Bowen (1961) and North and Byrne (1965). Rock in slide areas is predominantly sedimentary.

Destructive though they may be, landslides have had their role in shaping the indentations that lie between the points of land and have thereby made their contribution to the magnificent scenery at this locality. The coves that lie between Chapman and Ecola Points (Figure 12) and Ecola and Indian Points (Figure 13, 14) are both sites of ancient as well as active landslides. Bald Point, just south of Indian Beach, is the toe of an old landslide behind which is an active landslide area. The parking and picnic area at Ecola Point is on a landslide area that moved in February 1961 (Schlicker, and others 1961). Fortunately landslides in this locality move slowly, no more than a few feet a day, and take place during the winter months.

The rocks that lie off Chapman and Ecola Points mark former positions of these promontories, and the points once extended seaward much farther than the outermost rocks. As erosion continues the existing points will be destroyed, and their remnants will become units of the reefs as part of the very gradual but continuous change in scene along the shore.

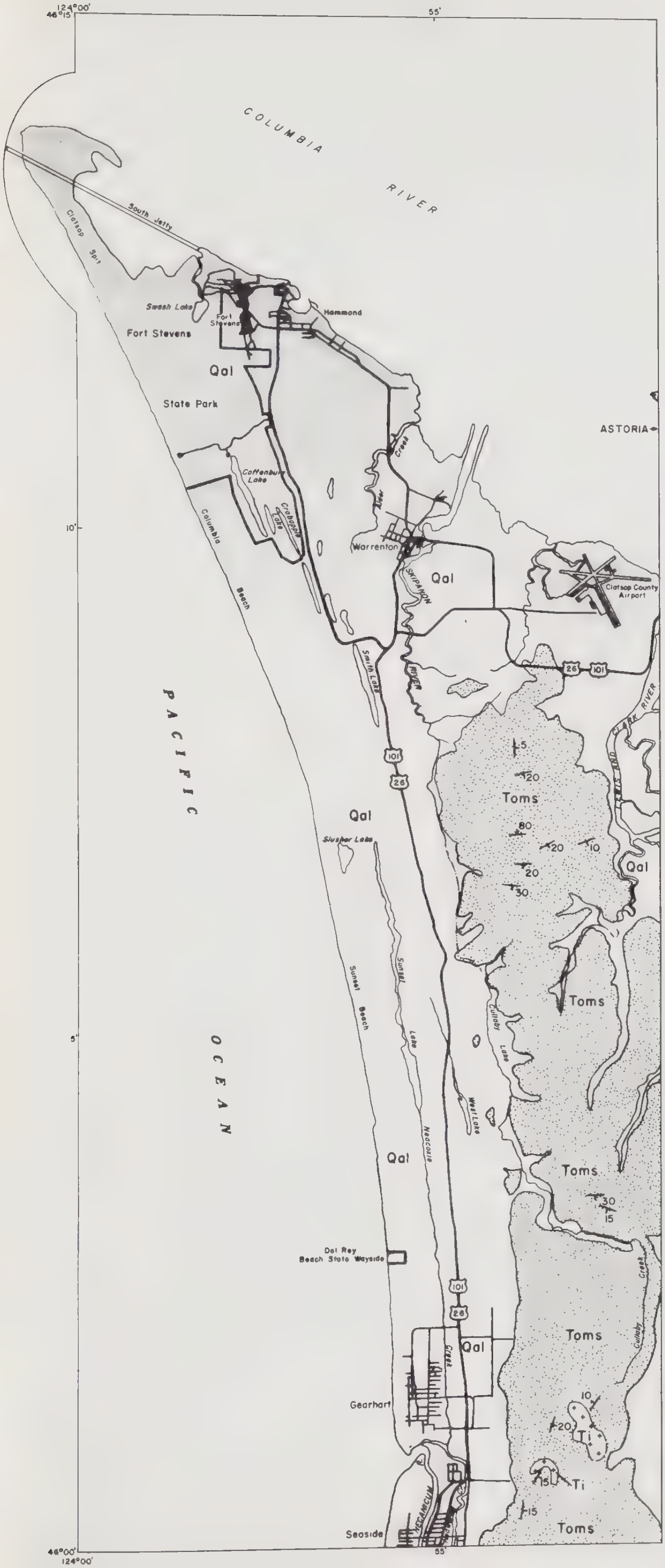
One of the most remarkable features of this part of the coast is Tillamook Rock (Figure 15), a 100-foot high basalt sea stack that lies a little more than a mile west of Tillamook Head. This stack, which was once part of the mainland, has survived the attack of the sea through the millenia that were required for the rock around it to be removed and the shore to be eroded landward to its present position. This stack is the site of Tillamook Lighthouse, which operated for more than 80 years until discontinued in 1962.

The main mass in the complex, Tillamook Head, consists of two major lobes separated by a broad, crescent-shaped indentation (Figure 16). The basalt along the front of the headland is dense and without layering and is some sort of intrusive body, probably a thick sill. Sedimentary rock underlies the lower slopes on the north side of the head. A high, steep cliff bounds Tillamook Head, and at numerous places, especially around the south side, indentations cut into bodies of sedimentary rocks impart an irregularity to the shore line. Narrow, rocky beaches that are not easily accessible lie at the base of the sea cliff.

Northern segment (map 3)

Stretching from Tillamook Head northward to the Columbia River is a strip of coastal lowland, the Clatsop Plains (Figure 16), which is covered mainly by dunes. At its southern end the strip is a little more than a mile wide, and in its northern part it is about 3 miles wide. The plain extends eastward along Young's Bay as river alluvium, and alluvial plains extend southward from it along Young's River and Lewis and Clark River.

MAP 3
Tillamook Head to Columbia River



EXPLANATION

Qal	Alluvium and dune sand
	UNCONFORMITY
Ti	Intrusive rocks Middle to late Miocene basaltic intrusive rocks which include thick sills
	UNCONFORMITY
Toms	Oligocene to Miocene sedimentary rocks Over 5,000 feet of thin-bedded to massive, medium-gray to dark-gray, tuffaceous siltstone and claystone with subordinate amounts of sandstone and shale locally
U D	Faults Dashed where approximately located or indefinite, dotted where concealed U, upthrown side; D, downthrown side
—— - - -	Contacts Dashed where approximately located
45	Approximate strike and dip of beds or flow
	Active landslide

Scale in Miles

1 .5 0 1 2 3

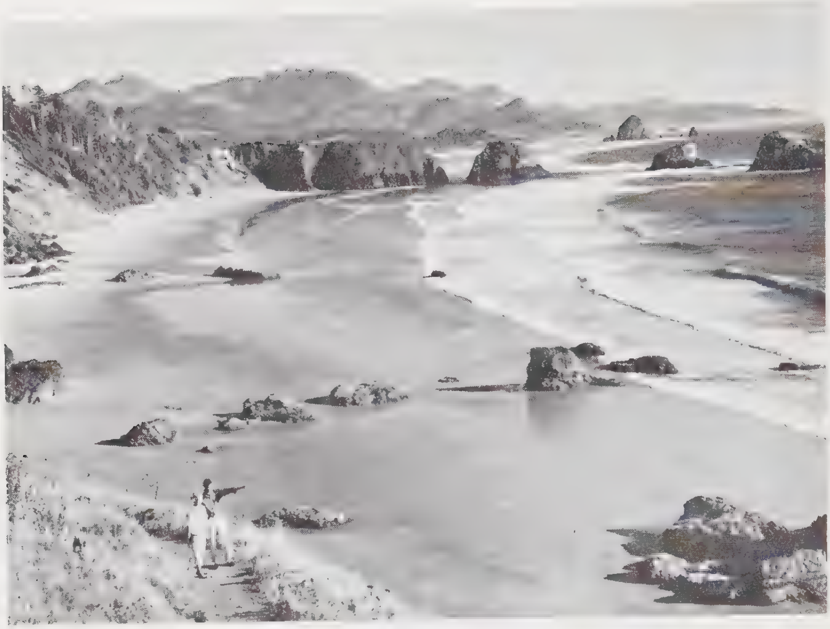


Figure 12. Crescent Beach viewed from Ecola Point. Chapman Point, at its south end, appears to be a remnant of a basalt sill. Beyond are Cannon Beach and Haystack Rock. The mountains that form the skyline are of basalt. (Oregon State Highway Div. photo)

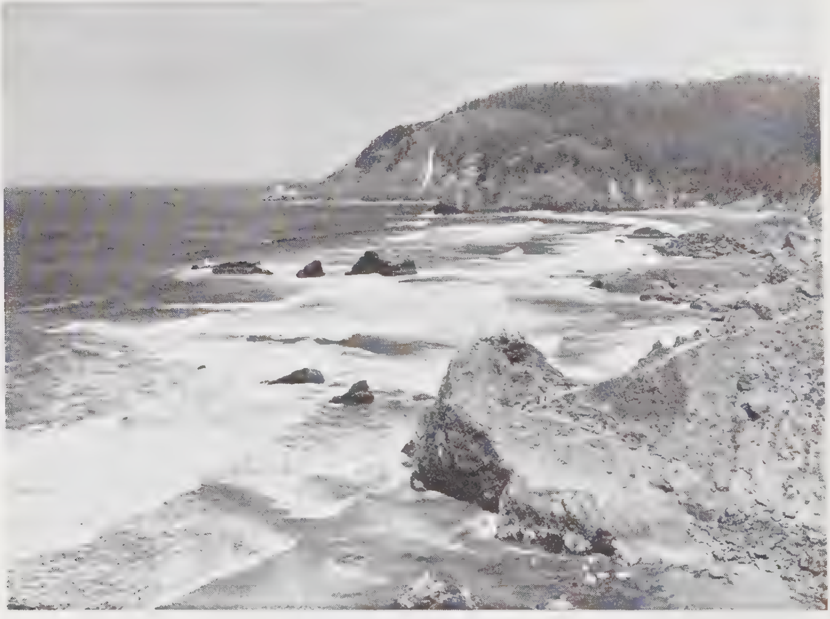


Figure 13. Indian Beach in the upper right of the photograph, is bounded on the north by Indian Point, composed of basalt, and on the south by Bald Point, the toe of a landslide. The sea caves at lower right are in basalt overlain by sedimentary rock. (Oregon State Highway Div. photo)

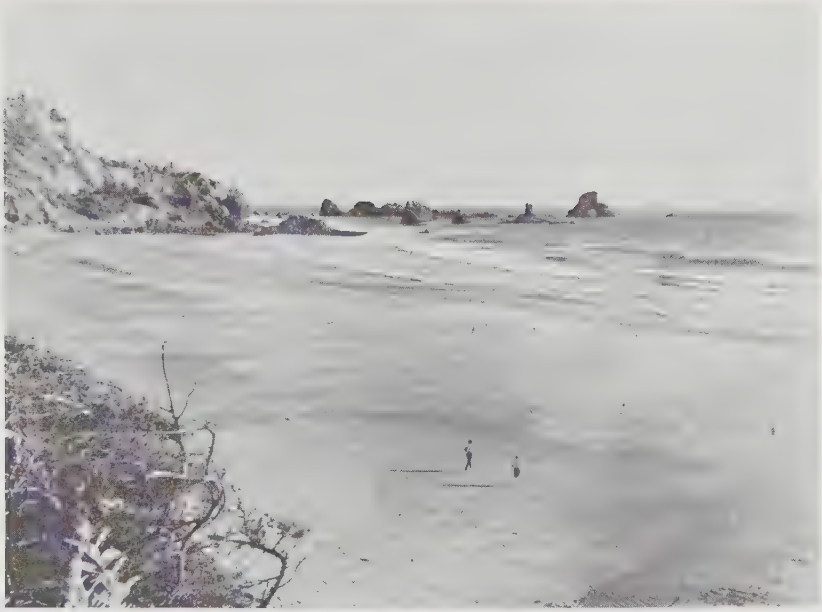


Figure 14. Indian Beach and Bald and Ecola Points. Sea Lion Rock, near the end of the reef off Ecola Point, is an arch. The rock in the reef is principally basalt, but some complexly folded sedimentary rock is intermixed with it. (Oregon State Highway Div. photo)

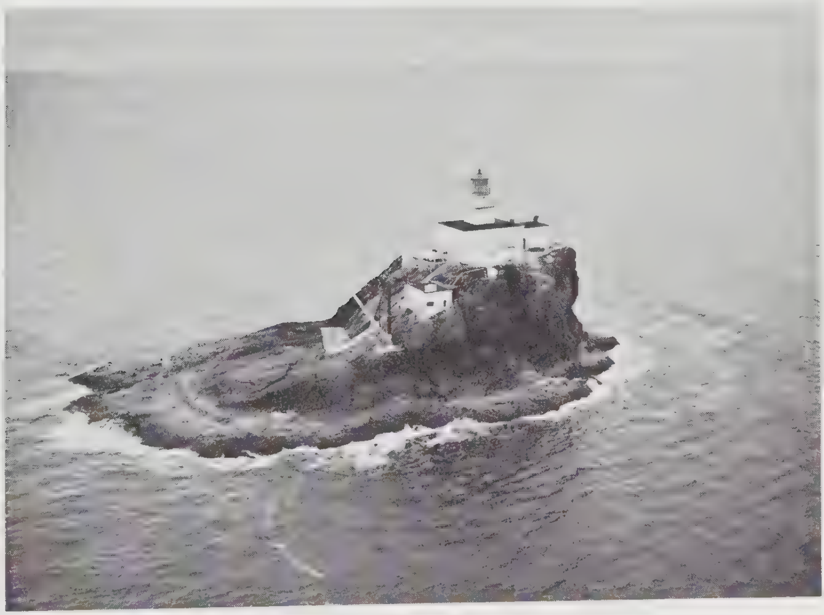


Figure 15. Tillamook Rock is a basalt sea stack lying about a mile west of Tillamook Head. Use of the lighthouse was discontinued in 1962 after 80 years of service. (Oregon State Highway Div. photo)

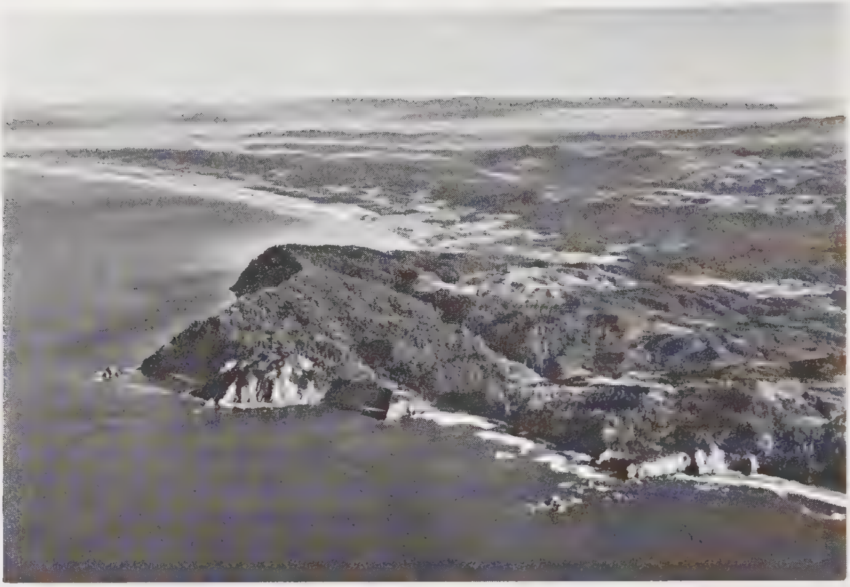


Figure 16. Tillamook Head, a basalt headland, is the central feature of this aerial photograph. The Clatsop Plains extend northward to the Columbia River in the distance. Indian Point is at center of photograph, and Ecola Point is at right of center. (Univ. Calif. Hydraulic Eng. Lab. photo)

The dunes of the Clatsop Plains are described and their origin is well explained in a book on the dunes of the Oregon and Washington coast by Cooper (1958), and the writer of this article draws heavily from Cooper's work. A map that shows the distribution of Tertiary bedrock, dunes, and alluvium accompanies an article on the hydrology of the Clatsop Plains by Frank (1970).

Dunes of the Clatsop Plains are impressive in the extent and uniformity of individual dune ridges and their parallel arrangement with each other and with the shoreline (Figure 17, 18). Ridges that vary only slightly in height and width and that curve gently to conform to the shoreline can be traced for long distances, in places for miles.

The Clatsop Plains is an area of fill where sand has been deposited parallel to a westward shifting shoreline along a coastal indentation which extends from Tillamook Head in Oregon to Cape Disappointment in Washington. Filling (prograding) began some time after sea level reached its maximum height following the most recent glaciation, and the origin of the dunes is closely tied to the prograding of the shore.

Prior to prograding, the shore was along the Tertiary upland, and the mouth of the Columbia River lay between Cape Disappointment on the north and the upland east of the Skipanon River on the south. Cooper (1958) believes that building of the plains was initiated by the deposition of a northward-projecting sandspit at the south side of the mouth of the Columbia River and that progradation along the shore began with construction of a sand bar in front of what is now Cullaby Lake. This was followed by the building of a succession of sand ridges along the shore as the beach shifted westward. Most of the ridges originated as foredunes. Sand transported mainly

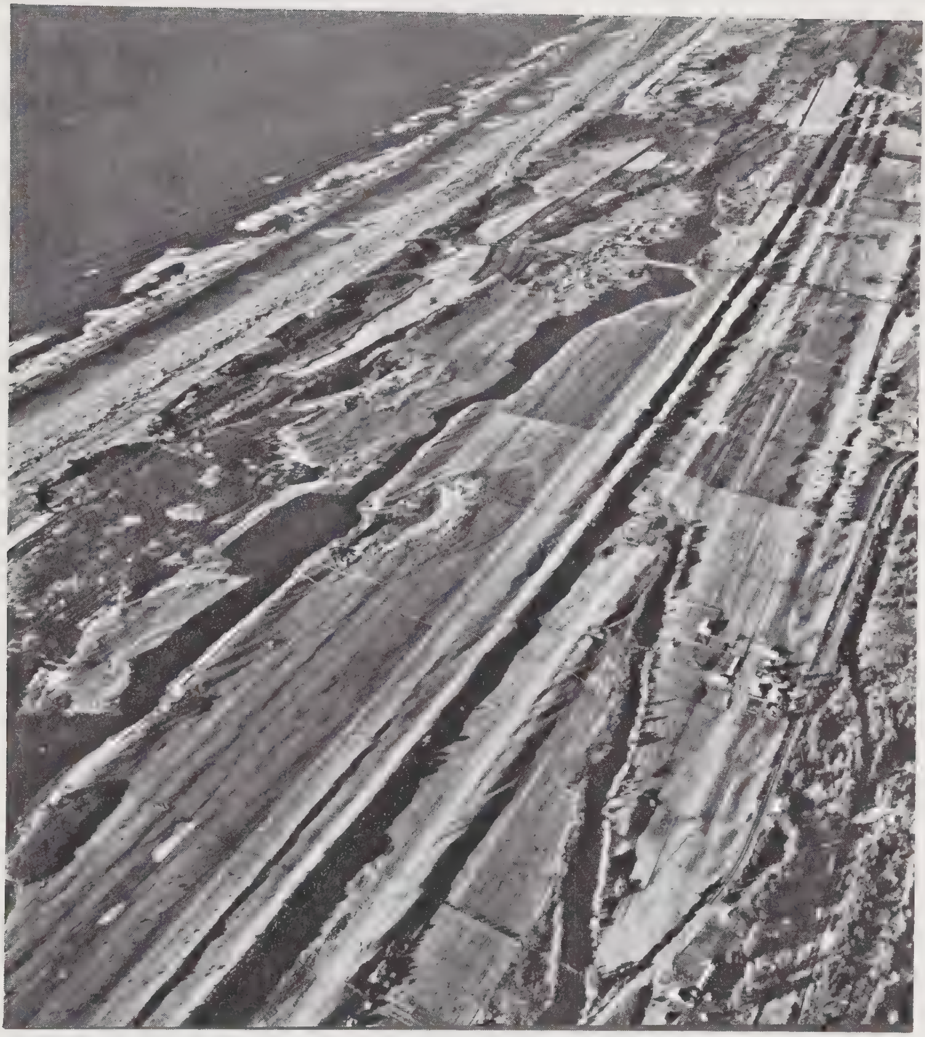


Figure 17. Dune ridges and lakes on the Clatsop Plains. Sunset Lake is the long one extending from the lower left corner of the photograph. Though it doesn't conform strictly to a single interdune valley, its shape is determined by the ridge-valley pattern. The north end of West Lake, right of center in the lower part of the photograph, cuts diagonally across the ridge-valley pattern and probably was a channel that connected to the sea when the shore stood along the edge of the dune ridge immediately west of it. (Univ. of Calif. Hydraulic Eng. Lab. photo)

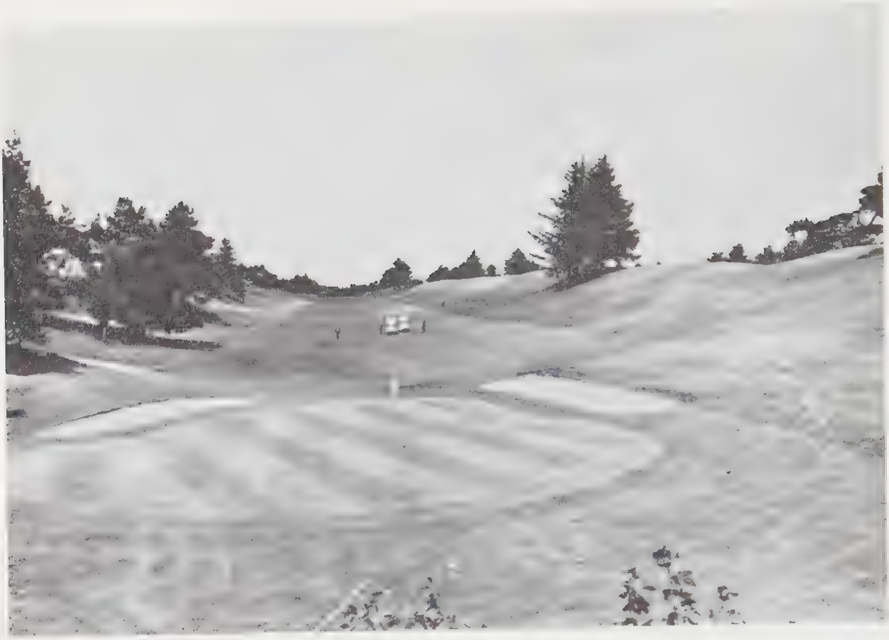


Figure 18. Green and fairway (hole 14) in an interdune valley on the Astoria Country Club golf course.

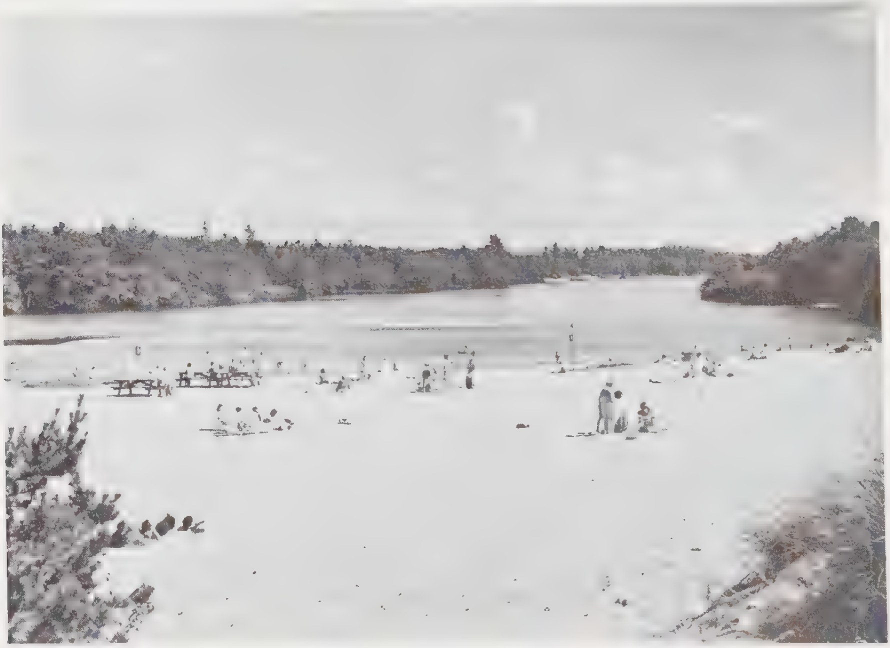


Figure 19. Coffenbury Lake in Ft. Stevens State Park is one of the largest interdune lakes on the Clatsop Plains. (Oregon State Highway Div. photo)

by the south-flowing summer currents washed up onto the beach, where it was picked up by wind and redeposited just behind the beach. Cooper believes that where a ridge has a wide strip of bog or a lake of considerable size behind it, origin as an offshore bar is indicated. Once a bar becomes exposed above sea level, it comes under the influence of the wind, and its size is increased by the addition of wind-blown sand.

Point Adams was the terminus of the sandspit that initiated progradation and was the end of land until the beginning of jetty construction in 1885. With the building of the south jetty, sand filled in over the shoal area off Point Adams to form Clatsop Spit. A wedge-shaped area of new land that is about half a mile wide at Fort Stevens was built up along the shore south of the spit. Sand was added to the beach as far south as Seaside, and parts of the beach that were formerly rocky are now covered with sand. A foredune ridge stabilized by marram grass lies behind the beach at Clatsop Spit and continues along the shore to the south, where it widens out into a terrain of grassy hillocks. South of Sunset Beach the hillocks give way to a narrow, grassy plain that lies between the beach and the first dune and extends to the mouth of the Necanicum River.

The numerous lakes on the Clatsop Plains owe their origin to the dunes. Most occupy depressions in the interdune valleys and are generally elongate in the direction of the ridges. Sunset (Figure 17), Coffenbury (Figure 19), and Smith Lakes are examples of this type. Cullaby Lake was impounded against the upland by dune sand, and the configuration of its eastern edge conforms to the erosional surface on the upland. Valleys in the topography became the finger projections of the lake and the dividing ridges the points of land between the fingers.

Many of the lakes have no surface outlets or appreciable inlets. The level of the lakes conforms to the level of the ground water table, and movement of water into and out of the lakes is by percolation through the sand. Sunset Lake has an outlet in Neacoxie Creek, which, although it is located within half a mile of the ocean at the point it leaves the lake, must flow southward about 4 miles to join Neawana Creek and the Necanicum River before it enters the ocean. The Necanicum River, which is deflected northward nearly 3 miles by a rock and sand barrier, is the only stream that crosses the beach between Tillamook Head and the Columbia River. North of it the wide, gently sloping beach extends without interruption for more than 15 miles.

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Glossary

Alluvium: Sediment deposited by streams.

Basalt: Dark-colored, fine-grained rock of volcanic origin.

Bedrock: Solid rock beneath soil or sediment layer. May be exposed.

Dike: Tabular-shaped intrusive igneous body that cuts through another rock.

Estuary: Lower part of river affected by tides and mingling of salt water from the ocean with fresh water of the river.

Foredune: Dune ridge that forms just behind and parallel to the beach.

Formation: 1. Land form. 2. Body of rock, the parts of which are related in space, time, and/or origin, such as Astoria Formation.

Igneous: Refers to rock formed from molten matter (magma) that originates deep below the earth's surface.

Intrusion: An igneous rock body that solidifies below the surface of the earth where magma invades older rock.

Joint: In geologic language, a fracture or parting which interrupts the physical continuity of a rock mass.

Quaternary: The latest Period of geologic time; began about 2 million years ago. Includes Pleistocene (Ice Age) and Holocene (recent) Epochs.

Sea stack: Small prominent island of bedrock near shore.

Shale: Laminated sedimentary rock made of solidified mud.

Shear zone: A zone in a rock body where the rock has been broken into fragments by fracturing and shearing.

Sill: A tabular-shaped intrusive igneous body that has been emplaced parallel to the bedding of the intruded rock.

Terrace: Bench-like landform cut into bedrock or built up by sedimentary deposition. Oregon shore terraces have aspects of both.

Tertiary: Period of geologic time between 65 million and 2 million years ago. Includes Paleocene, Eocene, Oligocene, Miocene, and Pliocene Epochs in order of decreasing age.

* * * * *

NEWPORT AREA MAPS ON OPEN FILE

The U.S. Geological Survey has released on open file three preliminary bedrock geologic maps of six quadrangles in the area of Newport, Oregon, by P. D. Snavely, Jr., N. S. MacLeod, and H. C. Wagner. The maps are printed in black and white on three sheets as follows: Cape Foulweather and Euchre Mountain, Yaquina and Toledo, and Waldport and Tidewater quadrangles. They are available for inspection at the Oregon Department of Geology and Mineral Industries in Portland, and copies can be purchased at $1.00 per sheet at a scale of 1:62,500, or $1.50 per sheet at a scale of 1:48,000. If ordered by mail, add 10 cents per sheet for cost of mailing.

* * * * *

COLEBROOKE SCHIST DESCRIBED IN SURVEY BULLETIN

"The Colebrooke Schist of Southwestern Oregon and its Relation to the Tectonic Evolution of the Region," by R. G. Coleman, has been published as Bulletin 1339 by U.S. Geological Survey. The 61-page bulletin with one plate in pocket is for sale by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. The price is $1.00.

The Colebrook Schist occurs in the Klamath Mountains in western Curry and Coos Counties. It consists of sediments and lavas similar to the Galice Formation which were metamorphosed in Early Cretaceous time and in Late Cretaceous were thrust on top of shelf and trench sediments that range in age from Late Jurassic to Early Cretaceous.

* * * * *

ASSESSMENT WORK NECESSARY TO RETAIN MINING CLAIMS

A change in Federal government regulations which became effective September 9 says that persons claiming minerals under the Mining Claim Act of 1872 must do the $100 annual assessment work or face loss of their claim. The change was announced by Archie D. Craft, State Director of Bureau of Land Management, the agency which administers the mining laws in Oregon.

The new regulations say that failure of a claimant to do the annual work in either labor or improvements will render the claim subject to cancellation. Failure will also subject the claim to relocation by another party unless the original locator or his successors in interest resume the annual work before someone else "jumps the claim."

Craft said, "We anticipate the new rules will help appreciably in clearing titles to public lands which are clouded by abandoned or dormant mining claims."

* * * * *

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Many people, if asked about minerals mined in Oregon, would not think of sand and gravel. Yet the mining of sand and gravel constitutes over a third the mineral production in Oregon -- $26 million in 1970. Some of its many uses:

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- Railroad ballast
- Riprap and jetty stone
- Filter sand
- Sandblasting
- Exposed aggregate
- Fill material
- Engine sand
- Sand traps (golf)
- Cigarette urns
- Poultry grit
- Floor sweep
- Leachate field fill
- Sand drains
- Moulding sand
- Mortar sand
- Stucco sand
- Road and highway construction
- Landscaping (sand, cobbles, boulders)
- Pebble mills (grinding media)
- Cobblestones and flagstones
- Highway sand (icy pavements)
- Artificial beaches
- Grinding and polishing
- Roofing sand and gravel
- Percolation tower fill (chemical process industry)
- Percolation tank fill (sewage treatment)
- Aggregate for French drains
- Aggregate for plunge-pool energy absorption
- Sand for vehicular emergency speed reduction traps
- Sand for egg timers
- Make-weight and ballast for hollow objets d'art
- Ballast for "squaw" fence posts
- Wire saw sand
- Plaster sand

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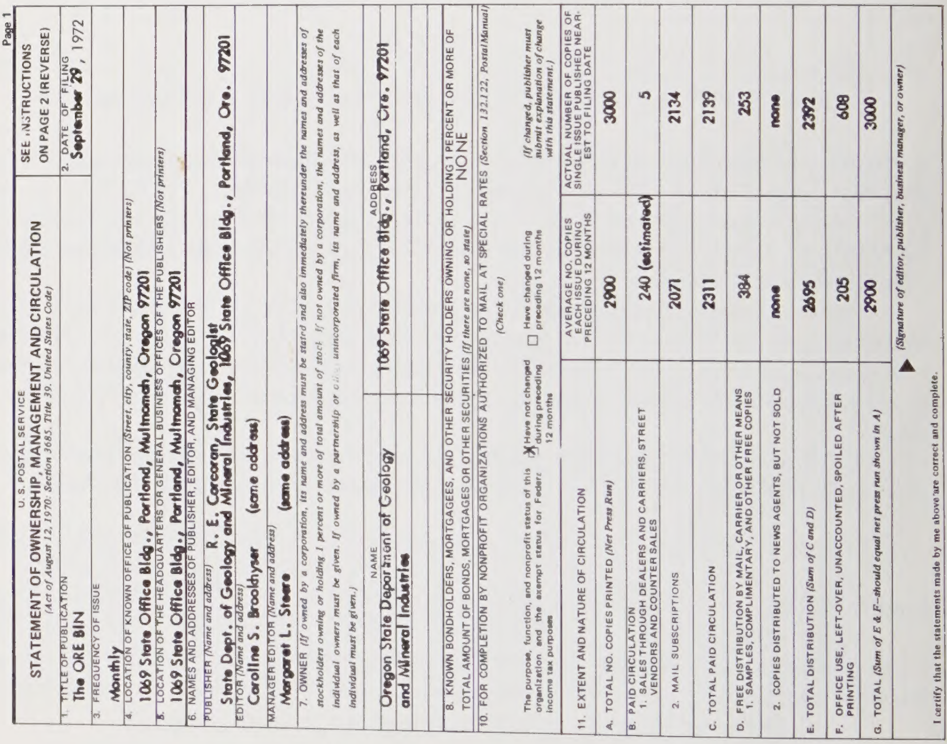

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2. DATE OF FILING: September 29, 1972

3. FREQUENCY OF ISSUE: Monthly

4. LOCATION OF KNOWN OFFICE OF PUBLICATION *(Street, city, county, state, ZIP code) (Not printers)*: 1069 State Office Bldg., Portland, Multnomah, Oregon 97201

5. LOCATION OF THE HEADQUARTERS OR GENERAL BUSINESS OFFICES OF THE PUBLISHERS *(Not printers)*: 1069 State Office Bldg., Portland, Multnomah, Oregon 97201

6. NAMES AND ADDRESSES OF PUBLISHER, EDITOR, AND MANAGING EDITOR

PUBLISHER *(Name and address)*: R. E. Corcoran, State Geologist
State Dept. of Geology and Mineral Industries, 1069 State Office Bldg., Portland, Ore. 97201

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